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THE LIBERATION OF NATIVE SOIL POTASSIUM INDUCED BY DIFFERENT CALCIC AND MAGNESIC MATERIALS, AS MEASURED BY LYSIMETER LEACHINGS

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Received for publication December 24, 1919

Ultimate analyses of the heavier types of soils usually demonstrate the occurrence of an abundance of potassium. Parallel water and acid extractions further demonstrate that such stores of potassium are usually retained with great tenacity. However, laboratory studies show that an added solution of a neutral salt of one alkali, or alkali-earth element, may effect the liberation of an approximate equivalence of another element locked within the soil, if contact between soil and salt solution is maintained for an appreciable period. After contact with soils, neutral solutions of calcium nitrate, calcium sulfate, calcium chloride, calcium acetate, and similar calcium salts are found to contain salts of magnesium and potassium, particularly where protracted contact is permitted before the soil suspension is filtered from the extracting solution. While it is seldom, if ever, contended that the amounts of soluble neutral salts added to the soil as components of fertilizer materials, would effect a liberation of potassium sufficient to care for maximum crop production, it has nevertheless been taught that this basic exchange may be of such magnitude as to be considered of practical value. It is obvious, however, that in humid regions field conditions would not be encountered, ordinarily, where the active mass of the free soil-water solution forcing an exchange would attain such freedom of movement and intensity of action as would be maintained under laboratory conditions.

In the application of the principle of basic exchange under field conditions, it has been assumed that carbonate of lime will function as do the more soluble neutral salts; for, among the benefits advanced, as possibly accruing from the use of lime, we find frequent mention of the supposed liberation of potassium to the growing plant. Granting that in practice the soluble neutral salts of calcium may liberate appreciable amounts of potassium, it seems hardly conservative to deduce that the same function may be inherent with the relatively weak solution of $CaCO_3$ in the carbonated water of the soil. It would seem quite possible that the speed of the hydrolysis of potassium minerals, effected by the carbonated water of the soil, may reach the possible maximum under the existing conditions of surface and temperature without any acceleration to be accredited to calcium carbonate carried in solution by the soil water.

Indeed, the results offered by Plummer (27) would seem to establish this point in so far as the original potassium-bearing minerals are concerned. However, we do not know that the solubilities of the crushed lump minerals are absolutely comparable to those of residual fragments of the same minerals, when the latter have been included in the soil mass for ages.

The work of Parker (25) indicates that, in their liberative action, soluble neutral salts of calcium function in a different manner (or at least with much greater intensity) from that to be expected from applications of either burnt lime or ground limestone. According to Parker's interpretation of the supposed base-exchange reaction in soils, the calcium-ions of a neutral salt are absorbed by the soil and, in effect, thereby generate HCl, which then extracts potassium from the soil's potassic complexes. The addition of NaOH, in amounts empirically determined as sufficient to neutralize the acid thus engendered, will inhibit the extraction of potassium effected by the engendered acid.

However, were carbonate of lime added to a soil, the calcium-ion would be absorbed and the weak CO_3-ion liberated; and, as differing from the generation of HCl incident to the absorption of the basic ion of a neutral chloride salt, this might result in a loss of CO_2 to the atmosphere, through the subsequent dissociation of H_2CO_3; or, on the other hand, it might result in a more concentrated CO_2 content in the soil-water solution effective for bathing the potassic minerals, or complexes derivative therefrom. The potassium thus coming into solution would be a measure of the readiness of the potassic complexes to undergo hydrolysis. In principle, but in extent possibly governed by surface of the applied amendment, the same reasoning would apply to both burnt and hydrated lime, as well as to limestone. For the work reported by MacIntire(21) has demonstrated that a surface application of finely divided burnt or hydrated lime will revert to the carbonate within an exposure period of four or five days prior to inworking.

LABORATORY AND POT STUDIES

The problem of augmenting available potassium has been studied in both laboratory and pot experimentation. Gaither (12) concluded from his studies at the Ohio Agricultural Experiment Station that little, if any, potassium is made available by the action of lime on soils. Gaither also gave analyses of wheat grown upon limed plats at the Ohio station. These analyses show that the application of lime has resulted in a depression in the potash content of the wheat ash. This depressive tendency of lime was likewise demonstrated by the analyses of wheat, grain and straw, from the limed plats of the Pennsylvania Agricultural Experiment Station, reported by MacIntire (19). Lyon and Bizzell (18) found no potassium enrichment in the ash of plants from limed soil, when averaging the potassium content of maize, oats, wheat, and grasses grown in their lysimeters during a period of four years.

In the study of the effect of additions of lime upon soil potassium, Gaither (12) was unable to obtain conclusive data in making water extractions. He then utilized N/5 HNO_3, the extracting period extending over 5 hours. In this case Volusia silt loam was used. The soil had been treated with varying amounts of lime, equivalent to rates of 2, 4, 6, 8, 10, 12, 15, 18, 20, and 25 tons of CaO per acre, after which two crops of alfalfa were grown. Just prior to the harvesting of the second crop of alfalfa, the soil samples were taken for extraction. The average of the two extractions from the checks gave 0.0097 per cent K_2O, while the average of the 10 lime-treated pots gave 0.0094 per cent. From these data Gaither concluded, "The theory held, 'that lime added to the soil increases the amount of available potash in the soil,' is either erroneous or requires more positive proof than has heretofore been obtained before it can be accepted."

Morse and Curry (24) concluded that while some liberation of potassium may result from lime treatment, the liberated potassium is again absorbed by the soil. Patton (26), in a résumé of earlier work, cites the experiments of Treutler, demonstrating that gypsum will yield potash to soil percolates. Storer (31) writes that investigations "have shown that gypsum exerts a powerful action in setting free potash, which has been absorbed and fixed by the earth, that is to say, by double silicates in the earth." Storer also stresses the importance of his contention, that not only is it true that "gypsum sets free potash (as well as magnesia) for the use of the crop, but it causes potash to be transferred to the lower layers of the soil so that the roots can everywhere find a store of it." Storer offered data secured by Boussingault from analyses of two crops of clover. These data show an increased potash content in each crop of clover where gypsum was applied. It is further stated that "numerous trials of leachings from loams, in great variety, with a solution of gypsum have shown that much more potash, magnesia and soda can be extracted by this solvent than by mere water."

Bradley (3) mixed three soils with 1 per cent each of CaO and $CaSO_4$, separately, and maintained 20 to 25 per cent moist contact for 6 weeks. At the end of this period the soils were leached with distilled water and the extracted potash determined. Average parts per million of 19.9, 26.0, and 34.1 for the blank, CaO and $CaSO_4$ extractions, respectively, were obtained. However, in a 24-hour-contact study, with occasional shaking and using 50 gm. of soil and 1 gm. of CaO or 1 gm. of $CaSO_4$, followed by filtration through a Pasteur-Chamberland filter, an increase in soluble potash was found only in the case of the $CaSO_4$ treatment; the CaO treatment having effected a depression in the amount of potash as compared with that obtained in distilled water blanks. The same findings were obtained in using pegmatite for similar extractions. In stating that gypsum has been very beneficial to soils of western Oregon, Bradley (3) states, "Tests on a number of these soils with lime and gypsum under different conditions indicate that gypsum acts as an indirect fertilizer, while lime does not." No reference is made to the possible beneficial action

to be derived from the sulfur content of the gypsum. Bradley gives some interesting data upon the question of the long-continued use of gypsum upon the solubility of the residual potash. A soil which had received gypsum treatments over a period of 25 years was compared with the same soil in an adjoining field which had not received such treatment. The data are here given:

	UNPLASTERED SOIL	PLASTERED SOIL
	per cent	*per cent*
Potash soluble in HCl, 1.115	0.202	0.268
Potash soluble in HNO_3, N/5	0.050	0.069

From these data it would appear that the prolonged gypsum treatment had appreciably enhanced the solubility of the residual potash.

McMiller (23), using five soils and applying to each, separate applications of 1 per cent CaO and $CaSO_4$, after 3 months found an increase of 82 per cent in the water-soluble potash. In studies with granite-derived soils and their separates, Dumont (9) found that heavy additions of calcium sulfate and long-continued moist contact were instrumental in liberating potash; and that the liberation increased coincident with the decrease in fineness of the separates. Working with New York soils, Tressler (32) found that in some instances potassium was liberated from the more insoluble forms by the use of soluble lime salts. In the case of the relatively young glacial soils used by Tressler, the potash-bearing materials were probably, in the main, undisintegrated ground-up minerals, rather than the hydrolyzed residues characteristic of soils formed *in situ*. Andre (2) found that the solubility of the potash in microline, a potassic mineral commonly found in soils, was increased by treatment with $CaSO_4$.

Fraps (11), in pot studies involving particularly a study of the acid-soluble potassium and that taken up by plants, came to the conclusion that additions of $CaCO_3$ and $CaSO_4$ did not effect any appreciable liberation of soil potash, nor was there induced any increase in the potash assimilated by the several crops. Additions of $CaCO_3$ were found not to have increased the amount of active potash present in the several soils at the end of the period of experimentation.

In making 17 distilled water extractions from a number of the fertilizer plats at the Pennsylvania station, under and following oats, during a period between May 13 and September 30, Brown and MacIntire (5) found less potassium in the extracts from the limed plats than from those unlimed, after 29 years of liming. The average of the 17 extractions from the limed and manured plat no. 22 amounted to but 6.85 parts per million of potassium as compared with 8.30 parts per million as an average from plat 16, which received manure alone. Again, the burnt-lime plat no. 23 gave an average potassium concentration of only 6.0 parts per million as against 6.5 for the

check plat no. 24. Thus, while it might be assumed that lime may have induced the liberation of potash initially, the long-continued occurrence of the accumulated supply of carbonate of lime ultimately decreased the extent of potash liberation, or else enhanced the soil's tendency to reabsorb any potassium released from siliceous combination. In this connection it might be noted that about one-third of the lime accumulated over a period of 30 years was held as silicates, or other forms than $CaCO_3$, although the untreated check plats now show slight, and in some cases no lime absorption, as measured by the Veitch (33) method studies of Gardner and Brown (13). The residual K_2O found in these soils after 30 years of liming will be considered in another part of this treatise.

In considering the plant as an indicator of the availability of potash after treatments of lime, the results of Fraps (10), Gaither (12), Lyon and Bizzell (18) and those cited by Storer (31) suggest the consideration of the potash composition of crops grown on the lime plats of the Pennsylvania station. Such data are available. In 1910 MacIntire (19) studied the composition of the wheat crop from nine of the plats of tier 2. Liming produced no effect upon the potassium content of the grain. However, in the case of wheat straw, a considerable decrease was effected as a result of liming after a period of 29 years. The straw from the plat which had received 2 tons of burnt lime every 4 years analyzed but 0.94 per cent K_2O, as against 1.10 per cent in that from the check plat. Again, the straw from the lime and manure plat analyzed 1.02 per cent K_2O as compared with a K_2O occurrence of 1.21 per cent in the straw harvested from the plat which received manure alone. The entire crop from the untreated plat removed 16.1 pounds of K_2O per acre, while that from the lime plat removed 15.6 pounds. The plat which received 6 tons of manure without lime yielded K_2O at the rate of 37.6 pounds per acre, as against 34.9 pounds from the plat which received both lime and manure.

In summarizing the results from the Rhode Island Agricultural Experiment Station, Wheeler (34) concluded that a study of the soils of that state does not justify the assumption that lime is to be considered as an extensive liberant of soil potash.

Briggs and Breazeale (4) found that solutions of $Ca(OH)_2$ were inactive upon the potassium content of soil and also upon that of both pegmatite and orthoclase; while the solubility of the potash content of orthoclase was also depressed by $CaSO_4$. Calcium was likewise found to induce no acceleration in the absorption of potassium by wheat seedlings, when the seedlings were grown in contact with soil and orthoclase. Had there been present an abundance of potash resultant from liberation effected by treatment, the reverse would have been expected, for LeClerc and Breazeale (15) demonstrated that there existed a marked tendency on the part of the seedlings to take up particularly large proportions of potash at this stage of growth.

As a result of his pot and laboratory studies with a poor soil supplemented by additions of muscovite, biotite, orthoclase and microline, Plummer (27),

concluded that $CaCO_3$ treatment and calcium bicarbonate solutions do not, *per se*, increase the amount of potash available to the plant, as measured by either the plant or by N/5 acid. Lipman and Gericke (16) studied potash liberation induced by $CaCO_3$ and $CaSO_4$ from two soils, an Oakley blow sand and a Berkley adobe and also a greenhouse modification of the adobe soil, the latter having been made by mixtures of the original adobe soil and barnyard manure. Treatments were mixed throughout and moist contact permitted. After periods of approximately 1, 4, and $9\frac{1}{2}$ months for the Oakley soil, and $1\frac{1}{2}$, 4, and 10 months for the adobe soil, with somewhat comparable periods for its manure modification, 1:2 proportions of soil and distilled water were allowed to digest for 6 days prior to filtration through Pasteur-Chamberland pressure filters. The water solutions thus obtained showed no increase in potash from either the $CaCO_3$ or $CaSO_4$ treatment in the case of the blow sand. Some increase was obtained in the filtrations from the adobe soil, as a result of both $CaCO_3$ and $CaSO_4$ additions; and the same was true of its manure-mixture modification. The longer periods of contact induced no coincidental increase in water-soluble potash. The greenhouse modification gave a greater potash recovery than did the unmodified soil, though it is not evident what part of the increase is attributable directly to the potash content of the manure added. Working with 500-gm. portions of soil and maintaining contact with 60 per cent moisture-holding capacity for 19 weeks at 30°C., Ames and Boltz (1) secured data indicating the liberation of potassium from added or engendered $CaSO_4$, but not from additions of $CaCO_3$. The analyses were made upon extractions of distilled water in the proportion of 400 gm. of soil to 2500 cc. of water. In the case of the silt loam soil, $CaCO_3$ treatment depressed the extractable potassium, but the addition of dried blood, with and without $CaCO_3$, effected an enhanced solubility of native potassium.

FIELD STUDIES

The effect of lime as a liberative agency in increasing the availability of soil potash has been studied but little under practical field conditions, with supplementary laboratory investigations. The plats of the Pennsylvania station offer a splendid opportunity for such a study, if it is assumed that adequate accuracy of sampling can be attained. Such a study was made by the writer (20) in 1911. The results were reported as a part of a general lime study and would not be found easily, if at all, in a search for data on potash experiments. Then too, the potash results were but incidental in the general study and the discussion offered was therefore limited. In addition, the annual reports attain only a limited circulation. The results are therefore given *in toto* (table 1).

In this work, four similarly treated plats of the same numeral designation one from each tier, were sampled. Composite samples were made from ten borings taken from each of the four $\frac{1}{8}$-acre plats, at each of three depths. The total residual potash found in the upper 21 inches was taken as a measure of the activities of the several forms of lime in activating the outgo of potash.

Discussion of the data of table 1

In comparing the manure plats no. 16 with the lime and manure plats no. 22, we find that the two lower depths of the former give an average of 69,236 pounds as against 68,899 pounds for the latter, or practically identical results. However, the upper 7 inches of the lime and manure plats no. 22 had approximately 9000 pounds less of K_2O than had the corresponding zone of the plats receiving manure alone. This comparison would seem to indicate a considerable potash replacement in the surface zone, without any fixation of the liberated surface soil potash, as it leached down through the underlying zones. However, had potash been liberated by the additions of lime, it would seem

TABLE 1

The influence of 30 years of liming upon the residual potassium of the upper three 7-inch zones of Hagerstown silty clay loam of the Pennsylvania Station General Fertilizer Experiment plats—equal amounts used from each of the four tiers in making composite samples

SOIL ZONES SAMPLED	K_2O FOUND, POUNDS PER ACRE					
	Plats 16	Plats 22	Plats 23	Plats 24	Plats 33	Plats 34
	6 tons of manure biennially	2 tons CaO quadrennially and 6 tons of manure biennially	2 tons CaO quadrennially	Checks	320 pounds of gypsum biennially	2 tons ground limestone biennially
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
0–7 inches	75,544	66,574	66. 523	68,532	72,440	69,154
7–14 inches	72,645	70,076	68,714	68,673	67,312	65,653
14–21 inches	65,827	67,721	66,523	76,136	66,410	57,705
0–21 inches	214,016	204,371	201,760	213,341	206,162	192,512

* 2,047,500 pounds per acre 7 inches is used for calculations to pounds per acre.

that the clay subsoil would have undoubtedly functioned as an absorbent for downward moving potassium salts, as will be shown was the case with the similar Cumberland loam soil of the lysimeters.

In a comparison between the analyses of the limed plats no. 23, with the limed and manured plats no. 22, we find the surface zones to be practically identical in composition, while the lower zones average 67,618 pounds for plats no. 23, as against an average of 68,999 pounds for the corresponding zones of plats no. 22. Considering the mass of soil as represented by the soil-weight used in the calculations, and without attributing a part of the difference to potash absorbed from that supplied by the 90 tons of manure, the results are reasonably concordant. Where these two limed plats, no. 22 and 23, are compared with their corresponding checks, no. 16 and 24, some displacement of potassium is indicated. It should be noted, however, that while the upper two zones of the untreated plats no. 24 are practically identical, the lower zone

jumps to a content of 76,136 pounds. If it were assumed that the lowest zone of plats no. 24 was not truly representative and the average of the two upper zones were instead assigned to it, then in a comparison with plats no. 22 and 23 this hypothetical summation would indicate a loss of only 1437 pounds of K_2O in the case of the limed and manured plats no. 22 and but 4040 pounds for plats no. 23 which received lime alone. However, the total potash in the upper 21 inches of the control plats no. 16, which received manure alone, amounts to 214,016 pounds, as against 213,341 pounds for the check plats no. 24. Again, the substitution of the average amount of the upper two zones for the determined amount found in the lowest zone would give a total of 205,808 pounds for the check plats, as against 206,162 for the gypsum plats. Thus the $CaSO_4$ treatments amounting to 4,800 pounds over a 30-year period would have registered no potash liberation, if the average composition figure were used to replace that determined. It seems hardly probable that the sampling of the lowest zone of the composite of plats no. 24 is truly representative; however, the two comparisons, that of the total from the composite of the check plats no. 24 against that of the total of the composites of the control plats no. 16 and that of the check plats no. 24 against the gypsum-treated plats no. 33, would militate against the adoption of the total which would obtain, were the apparent error in the sampling of the lowest zone to be presumed as being rectified by the substitution of the value found by the process of averaging the figures obtained in the analyses of the two upper zones.

In further comparisons, the composite of the ground-limestone plats no. 34 shows a deficiency of potash amounting to 20,829 pounds for the entire 21 inches, as compared to the residual potash found in the composite of the check plats no. 24. This difference is manifestly of greater magnitude than would be chemically possible, in view of the determinations of the total residual lime and residual calcium carbonate at the same depths. Here, again, the third zone appears as abnormal, and since the apparent abnormality of the third zone sampling of plats no. 24 tends upward and that of plats no. 34 tends downward, the differential error is accentuated. It would, of course, be contrary to all chemical conceptions to assume that the amount of potash liberated by the ground limestone would be equal to that set free by the burnt lime under the imposed conditions of repetition over such a long period.

Considering the comparisons from another angle, it is very interesting to note that had the analyses been confined to the samplings from the two upper zones, and in particular had the manure control plats not been included, the conclusions would have been definitely and materially different. No potash liberation would have been indicated, 137,205 pounds having been found in the upper 14 inches of the composited check plats against 139,752 pounds for the gypsum plats. On the other hand, the comparison of 137,205 pounds for the check plats against 136,650 pounds, 135,237 pounds, and 134,807 pounds, would give a loss of potash amounting, respectively, to 555 pounds for the lime and manure plats, 1968 pounds for the burnt-lime plats and 2308 pounds for

the ground-limestone plats. Looking at the data from either viewpoint, that of the upper 14 inches, or that of the aggregate of the three 7-inch zones, but with reservation as to the commensurateness of sampling and analysis, it would seem reasonable to assume that the burnt-lime and ground-limestone treatments have effectuated some, though small, release and leaching of potash. Remembering the much lighter application of $CaSO_4$ and considering the mass of the soil sampled, the action of the total of 4800 pounds of $CaSO_4$ may be said to have been indefinitely established.

In discussing these results, in this connection, it is thought well to point out the limitations incident to representative sampling, even when there is exerted the most extreme care and the further limitation of interpretation of analytical results into positive terms on the acre depth basis. The accuracy and dependability of supposedly representative sampling are in no wise commensurate with the analytical procedure carried out in the laboratory. The results embodied in table 1 represent the true potassium content of the samples obtained; but the uncertainty as to their representative character necessitates reservations in the interpretation and acceptance of the findings and indications derived therefrom. Such difficulties and limitations possibly serve to emphasize the value and greater dependability of data secured through the medium of carefully controlled lysimeter experiments, where careful mixing of the soil mass assures a reasonably uniform composition of the soil used to fill the tanks.

Previous lysimeter investigations

As compared with laboratory extractions and percolating studies, there is a dearth of lysimeter investigations upon the subject of potash liberation and outgo induced by lime treatments. Such studies have been considered by some (Lipman (16), Tressler (32)) as being more indirect than direct. To the writer, it would appear that the actual static equilibria would be much more nearly indicated by the leachings obtained from exposure to actual precipitation, than by extractions under the accentuated conditions imposed during agitation with a surplus of solvent, after an exaggerated period of contact of treatment and soil, such as would not be encountered if the factors of solubility, outgo and absorptive tendencies were given free play. This would be particularly true in the case of the batteries where no subsoil was used.

Lyon and Bizzell (17, 18) have recently reported the results secured during the initial 5-year period in their lysimeter studies upon a Dunkirk clay loam. The analysis of leachings gave no indication of any liberation of potassium to the free soil water as a result of one application of burnt lime at the rate of 3000 pounds per acre. However, since the applications of potassium sulfate likewise failed to show any enrichment in the potassium content of leachings, it is recognized that the underlying 3 feet of soil might have effected the absorption of some fraction of the total of potassium salts which might have

passed from the surface soil. Although the average crop analyses show that the plants utilized about twice as much potassium as was leached under fallow conditions, nevertheless the outgo of potassium in leachings is apparently independent of the crop growth. This would suggest the possibility that the crops derived their stores of potassium from the potassium content of film water, rather than from that contained in the free water. The averages from annual analyses of corn, oats, wheat and grass for 4 years show a practically identical potassium content in the crops from the limed and unlimed tanks.

In their comprehensive memoir, Lyon and Bizzell (18) review the several aspects resulting from the data derived from lysimeter investigations reported. The results reported from the Florida, Texas, Hawaiian, Rothamsted, Bromberg, Göttingen, Jönköping and Cawnpore stations also are reviewed in some detail. From some of the above cited data and other publications, it might be assumed, and indeed it is generally held, that the loss of potassium from the soil through leaching is to be considered as negligible. Soil type, composition, age, method of cropping, periodicity and magnitude of rainfall, topography, range of seasonal temperature and other factors must have important bearing upon the extent of potassium outgo, which may truly have very wide range. Clarke (7) in offering the results of analyses of 203 samples of drainage water shows that, while more often occurring in relatively small amounts, potassium may be found as high as 160 parts per million. Greaves and Hirst (14) record the analyses of the water from 67 streams, 4 drains and 3 wells, giving amounts varying from a minimum of 0.79 parts per million to 25.3 parts per million. The maximum figure offered by them is greater than that secured in any annual period in the results offered in this paper. This is true even in the case of the 100-ton lime tanks.

LIME AND MAGNESIA LYSIMETER STUDIES AT THE TENNESSEE STATION

Storer (31) attributes to gypsum the function of liberation of soil potash, followed by its dissemination throughout a more extensive area, thus increasing the feeding zone of growing plants in search of nutrient potash. The lysimeter studies offered in this treatise are so planned that by the use of soil alone and soil with subsoil, any such migration following release by treatment may be recorded and some measure of the absorptive tendencies of the soil and subsoil obtained, thus throwing some light upon the phase of the problem pointed out by Storer.

In previously reported studies (21) based upon the use of Cumberland loam soil in field cylinders, different forms of lime were used in 2-ton and 8-ton per acre applications. As a result of those and other studies, further experiments were planned and begun in July, 1914, using lysimeters in which the minimum applications of burnt lime were at the rate of 8 tons, equivalent to the maximum amount used in the cylinder investigations. The lysimeter equipment has been previously described and illustrated (21) and is also shown in this contribution

(plate 1). Treatments equivalent to 32 tons and 100 tons per acre were also included in the later lysimeter experiments. In amounts chemically equivalent to these three amounts of CaO, treatments of MgO, precipitated $CaCO_3$, precipitated $MgCO_3$, 100-mesh limestone, 100-mesh dolomite, and 100-mesh magnesite were also included in the scheme of experimentation. Thirty-two-ton applications of wollastonite and of serpentine of 100-mesh fineness were also used in the deep tanks. Thus, in the surface-soil group, there were included, three CaO treatments, one each at the rates of 8, 32 and 100 tons per acre 2,000,000 pounds of soil. In like manner, three tanks of each of the other six, chemically equivalent oxide and carbonate materials were utilized. In this way, three surface-soil batteries of 7 tanks each, at the three rates, were incorporated in the experiment. These 21 surface-soil tanks were then duplicated exactly, save for the fact that the surface soil of the second series of 21 tanks rested upon 1 foot of well tamped, untreated clay subsoil. In addition there were also installed one blank surface-soil-only tank and one surface-and-subsoil tank.

The periodical leachings from the several tanks have been collected over a period of 5 years and a definite aliquot of each sample preserved in acid solution. Each annual composite thus obtained has been subjected to "complete" chemical analysis. This series of the 46 annual composites, for each of 5 years affords an excellent opportunity to gauge any enhanced outgo of potassium as the result of applications of nine different calcic and magnesic compounds in amounts up to the equivalence of 200,000 pounds of CaO per acre 2,000,000 pounds of soil.

In addition to the foregoing system of 46 tanks devoted to the study of the Cumberland loam, another battery of 22 tanks containing Cherokee sandy loam, surface soil only, has been under experimentation for 2 years. The leachings from this second set have been preserved and analyzed in the same manner as were those of the system of 46 tanks. While devoted primarily to the study of the outgo of sulfur from treatments of both native and applied sulfur, the second system affords an additional opportunity for study of the liberation of native soil potassium, as indicated by leachings. The treatments of this set will be described in prefacing the report of the results secured during the initial 2-year period and recorded in the latter part of this contribution.

In the scheme of experimentation with the two soils we have, therefore, a study embracing 11 calcic and magnesic treatments at several rates, from 9 additions, namely, CaO, MgO, $CaCO_3$, $MgCO_3$, limestone, dolomite, magnesite, wollastonite and serpentine; and 2 engendered compounds $CaSO_4$ and $MgSO_4$, where sulfur was added as $FeSO_4$, iron pyrites or sulfur together with lime or magnesia. Indeed, at certain periods, the formation of calcium and magnesium nitrates was of such magnitude as to be actually equivalent to treatments of those compounds.

The potassium content of the Cumberland loam and the Cherokee sandy loam

The potassium content *in toto*, and the relative solubilities of the aggregate of the potassic complexes are shown in table 2. The total potassium content was obtained by the J. Lawrence Smith disintegration procedure, described by Crookes (8). The N/5 acid digestion was at room temperature, with frequent agitations over a period of 5 hours. The HCl 1.115 digestion was carried out for 10 hours at the temperature of boiling tap water. The two samples of Cumberland loam were secured from approximately the same spot, but at different times. The two samples show close concordance in their amounts of acid-soluble potassium and total potassium. The clay subsoil used in tanks 22–44 and that used in tank 45 were from beneath the same soil,

TABLE 2

Acid-soluble and total potassium content of Cumberland loam and Cherokee sandy loam (moisture-free basis)

LABORATORY NUMBER	SOIL	USED IN TANKS NUMBER	POTASSIUM CONTENT					
			N/5 HNO_3 digestion 220-gm. charge		HCl 1.115 digestion 10-gm. charge		J. L. Smith fusion 1-gm. charge	
			Per cent	Pounds per 2,000,000 pounds of soil	Per cent	Pounds per 2,000,000 pounds of soil	Per cent	Pounds per 2,000,000 pounds of soil
3343	Cumberland loam.....	1–44	0.0097	194	0.244	4,880	1.004	20,080
4693	Cumberland loam.....	45–46	0.0103	206	0.248	4,960	1.007	20,140
3224	Subsoil.....	22–44			0.618	12,360	0.898	17,960
4694	Subsoil.....	45	0.0110	220	1.100	22,000	1.445	28,900
4893	Cherokee sandy loam...	50–71	0.0064	128	0.243	4,860	0.753	15,060

but both could not be secured from exactly the same spot because of building operations between the periods of sampling. Some difference in potassium content of the two subsoils is indicated by the analyses. As would be expected, the Cherokee sandy loam reflects its type in the potassium content determined by the analyses.

The 46-tank lime-magnesia system data

Tables 3 to 14 and figures 1 to 15

The potassium determinations upon the several annual composites from the original 46 tanks are given in tables 3 to 14, inclusive. The results were obtained by the use of the colorimetric method of Cameron and Failyer (6), as given by Shreiner and Failyer (29). Each annual outgo of potassium from both surface-soil and surface-soil-plus-subsoil tanks will be considered in order of sequence.

Initial annual period (tables 3 and 4). The volumes of leachings were fairly concordant, when the average of the three 7-tank surface-soil batteries are

TABLE 3

Amounts of potassium leached from Cumberland loam, surface soil only, in field lysimeters—July, 1914, to July, 1915

Treatments of CaO, MgO, $CaCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons, and 100 tons per acre 2,000,000 pounds of soil

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with soil	Rate per 2,000,000 pounds of soil				
		tons				
1	CaO	8	69.7	4.98	0.3472	15.3
2	MgO	=8	69.2	3.19	0.2205	9.7
3	$CaCO_3$	=8	74.4	7.47	0.5557	24.5
4	$MgCO_3$	=8	77.3	4.58	0.3542	15.6
5	Limestone	=8	82.0	3.98	0.3267	14.5
6	Dolomite	=8	67.2	2.44	0.1639	7.2
7	Magnesite	=8	74.0	1.84	0.1363	6.0
	Average	=8	73.4	4.07	0.3006	13.3
8	CaO	32	79.8	4.28	0.3417	15.1
9	MgO	=32	74.8	1.73	0.1292	5.7
10	$CaCO_3$	=32	81.5	3.98	0.3247	14.3
11	$MgCO_3$	=32	57.0	2.31	0.1315	5.8
12	Limestone	=32	81.6	2.24	0.1828	8.1
13	Dolomite	=32	78.2	1.73	0.1350	6.0
14	Magnesite	=32	81.7	2.09	0.1708	7.5
	Average	=32	76.4	2.62	0.2022	8.9
15	CaO	100	79.2	3.98	0.3156	13.9
16	MgO	=100	72.9	2.59	0.1889	8.3
17	$CaCO_3$	=100	68.5	2.37	0.1625	7.2
18	$MgCO_3$	=100	61.1	2.59	0.1582	7.0
19	Limestone	=100	82.4	2.37	0.1955	8.6
20	Dolomite	=100	61.0	5.26	0.3208	14.1
21	Magnesite	=100	71.8	1.73	0.1241	5.5
	Average	=100	71.0	2.98	0.2094	9.2
Average of all treated tanks			73.6	3.22	0.2371	10.5

compared. The potassium concentrations of the leachings from the 8-ton tanks average somewhat higher than do those from the heavier treatments of 32 and 100 tons. The CaO treatments appear to have exerted a greater tendency toward potassium outgo than did the corresponding MgO treatments.

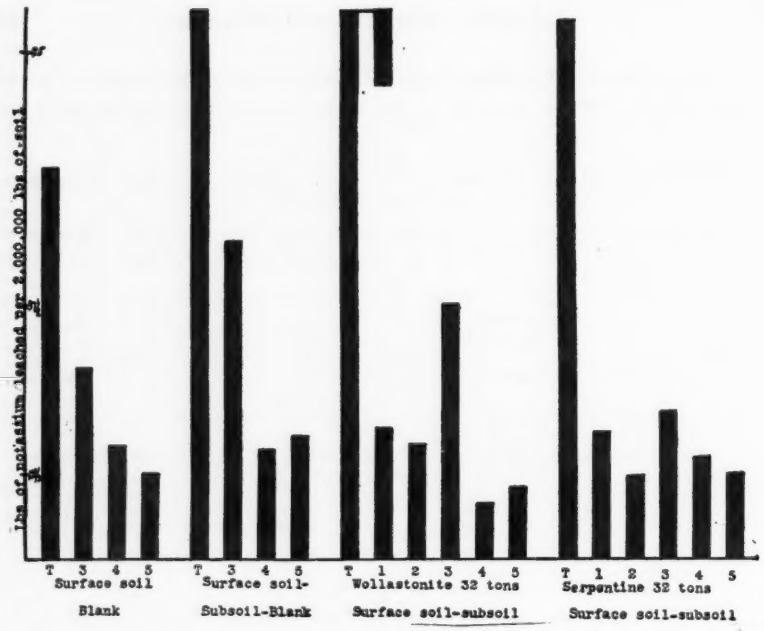

FIG. 1. NO-TREATMENT, WOLLASTONITE AND SERPENTINE TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

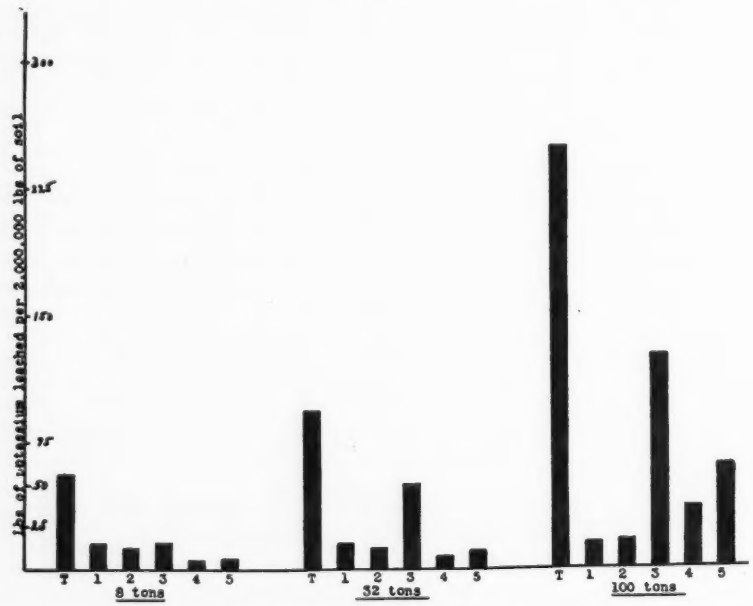

FIG. 2. BURNT LIME TREATMENTS, SURFACE-SOIL-ONLY TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

TABLE 4

Amounts of potassium leached from Cumberland loam, surface soil and subsoil, in field lysimeters—July, 1914, to July, 1915

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil—also wollastonite and serpentine at the rates of 32 tons

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with surface soil	Rate per 2,000,000 pounds of soil				
		tons				
22	CaO	8	73.2	5.48	0.4008	17.7
23	MgO	=8	66.4	5.38	0.3569	15.8
24	$CaCO_3$	=8	76.6	3.98	0.3050	13.5
25	$MgCO_3$	=8	55.4	5.98	0.3309	14.6
26	Limestone	=8	63.3	4.98	0.3153	13.9
27	Dolomite	=8	67.0	5.98	0.4006	17.7
28	Magnesite	=8	75.4	4.28	0.3229	14.2
	Average	=8	68.2	5.15	0.3475	15.3
29	CaO	32	73.2	4.58	0.3352	14.8
30	MgO	=32	62.7	5.98	0.3749	16.5
31	$CaCO_3$	=32	72.3	5.07	0.4825	21.3
32	$MgCO_3$	=32	84.6	5.48	0.4636	20.4
33	Limestone	=32	71.1	4.98	0.3542	15.6
34	Dolomite	=32	75.2	4.28	0.3222	14.2
35	Magnesite	=32	84.2	3.98	0.3354	14.8
	Average	=32	74.8	4.91	0.3811	16.8
36	CaO	100	87.5	4.28	0.3747	16.5
37	MgO	=100	90.2	4.28	0.3862	17.0
38	$CaCO_3$	=100	54.7	4.98	0.2724	12.0
39	$MgCO_3$	=100	55.5	1.33	0.0737	3.3
40	Limestone	=100	91.7	7.47	0.6848	30.2
41	Dolomite	=100	80.1	5.48	0.4387	19.3
42	Magnesite	=100	62.4	3.98	0.2488	11.0
	Average	=100	74.6	4.54	0.3542	15.6
43	Wollastonite	32	80.1	5.48	0.4390	19.4
44	Serpentine	32	85.3	3.98	0.4245	18.7
Average of treated tanks, except no. 43 and 44			72.5	4.87	0.3609	15.9

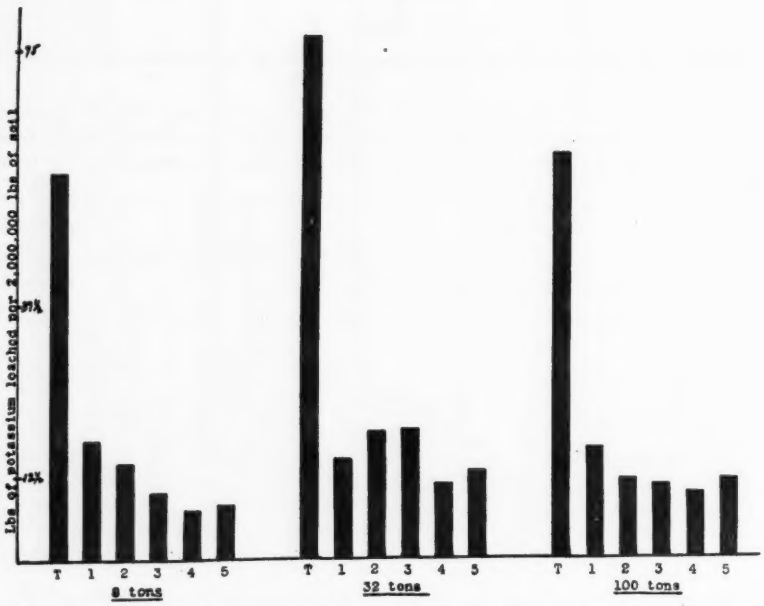

FIG. 3. BURNT LIME TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

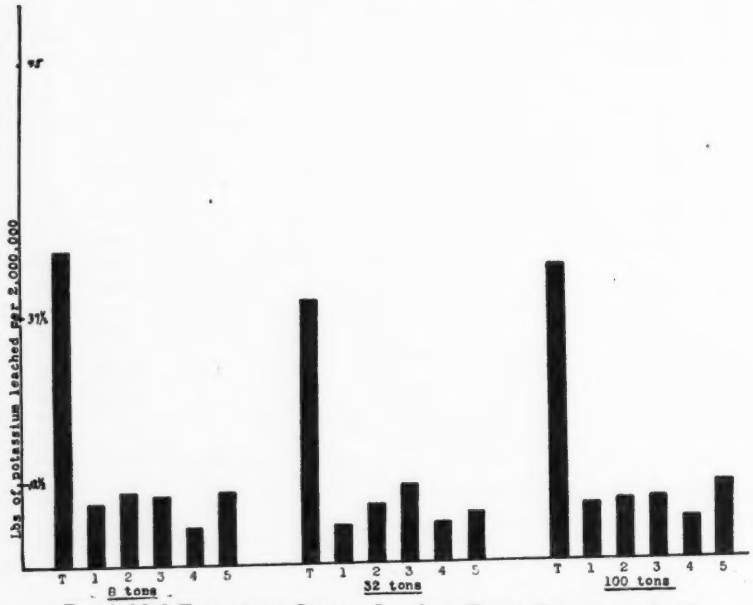

FIG. 4. MgO TREATMENTS, SURFACE-SOIL-ONLY TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

However, the extent of potassium leaching was not great in any instance, the maximum average being but 13.3 pounds per 2,000,000 pounds of soil. While the blank was not included during the initial two years, the first annual analysis of leachings from the untreated surface soil showed an outgo of 28.2 pounds during the third year, as against 46.7 pounds from the subsoil tank; however, the average of the 21 treated surface-soil tanks gave a volume leached of 167.6 litres for the third year, as compared to a corresponding average of 73.6 litres for the initial year. These comparisons would indicate no potash liberation, if not an actual depressed outgo during the initial year, as a result of surface-soil treatment without underlying subsoil.

A comparison between the 21 surface-soil tanks and the correspondingly treated tanks containing subsoil shows a slightly less average volume leaching, but a heavier average outgo of potassium. As a whole, the subsoil tanks gave an average potassium outgo of 15.9 pounds against an average of but 10.5 pounds for the surface soil. The most outstanding exception to this relationship is that of tank 39, which suffered a loss of but 3.3 pounds of potassium. However, because of the ameliorating effects induced by screening and placing, the results of the first year would hardly be considered as representing the normal relationship between the soils of the deep and shallow tanks. The data indicate that, during the initial year, the effect of screening and placing the subsoil was to accelerate its tendency to yield potassium to solution, rather than to enhance its absorptive properties.

Second annual period (tables 5 and 6). During the second year of exposure, the potassium leachings from the surface-soil and subsoil tanks were more nearly equivalent. The average outgo from the seven surface-soil tanks, each receiving 8-ton CaO equivalence, was 10.3 pounds as compared with 12.9 pounds for the corresponding deep cans; while the 32-ton surface tanks yielded 9.9 pounds as an average against 14.4 pounds for the corresponding subsoil tanks. On the other hand, the 100-ton treatments gave practically identical averages, namely, 13.2 pounds and 13.1 pounds, respectively, for the corresponding surface-soil-subsoil tanks. The second annual period gave 16.9 pounds for the surface-soil blank as against 16.1 pounds for the subsoil blank. The difference between the results induced by the CaO and MgO treatments was not nearly so marked nor extensive during the second year, especially in the case of the subsoil tanks.

All of the tanks have been analyzed at several periods for occurrences of residual $CaCO_3$. The results showing these residual occurrences have been offered by the writer (21). These data demonstrate that during most of the first year and thereafter, the 8-ton CaO treatments may be considered as being identical to treatments of $CaCO_3$, all of the oxide having reverted to the carbonate. The MgO and $MgCO_3$ 8-ton treatments, however, do not maintain the same parallel in carbonation. These results are to be later offered in detail. Suffice it to say that the applied $MgCO_3$ had undergone practically complete disintegration, resulting in liberation of CO_2 and fixation of magnesium; while

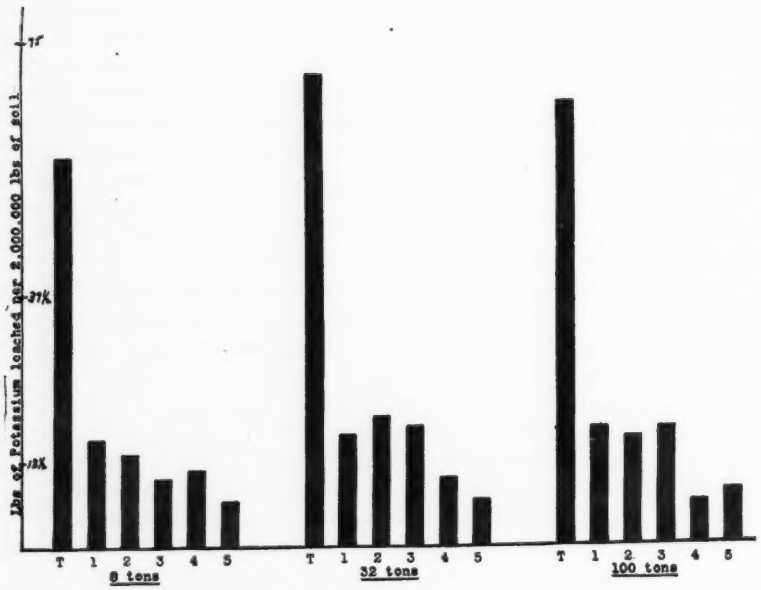

FIG. 5. MgO TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

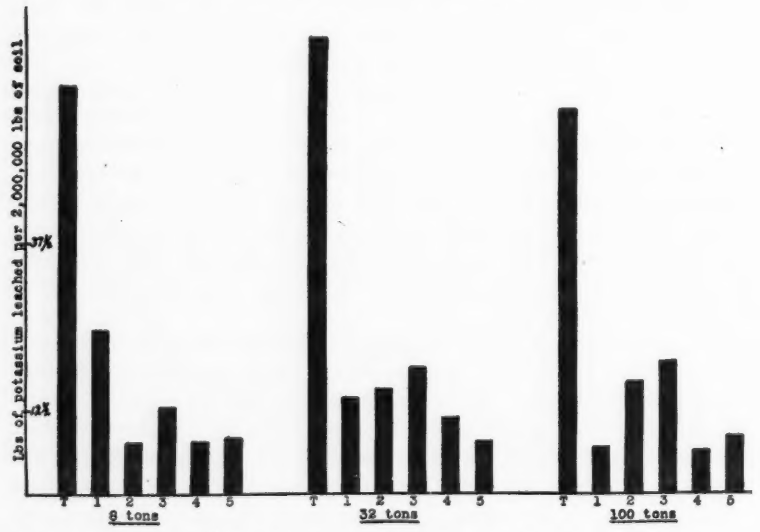

FIG. 6. PRECIPITATED $CaCO_3$ TREATMENTS, SURFACE-SOIL-ONLY TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

TABLE 5

Amounts of potassium leached from Cumberland loam, surface soil only, in field lysimeters—July, 1915, to July, 1916

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre, 2,000,000 pounds of soil

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with soil	Rate per 2,000,000 pounds of soil				
		tons				
1	CaO	8	136.8	1.99	0.2725	12.0
2	MgO	=8	116.3	2.21	0.2567	11.3
3	$CaCO_3$	=8	116.7	1.48	0.1716	7.6
4	$MgCO_3$	=8	143.7	2.09	0.3005	13.3
5	Limestone	=8	129.2	1.59	0.2058	9.1
6	Dolomite	=8	107.7	1.81	0.1948	8.6
7	Magnesite	=8	130.0	1.81	0.2352	10.4
	Average	=8	125.8	1.85	0.2339	10.3
8	CaO	32	113.9	2.32	0.2638	11.6
9	MgO	=32	108.1	1.81	0.1956	8.6
10	$CaCO_3$	=32	118.5	3.02	0.3580	15.8
11	$MgCO_3$	=32	98.9	1.48	0.1461	6.4
12	Limestone	=32	124.7	1.48	0.1842	8.1
13	Dolomite	=32	127.0	1.81	0.2298	10.1
14	Magnesite	=32	137.7	1.43	0.1965	8.7
	Average	=32	118.4	1.91	0.2249	9.9
15	CaO	100	107.4	3.32	0.3566	15.7
16	MgO	=100	96.5	2.12	0.2019	8.9
17	$CaCO_3$	=100	104.1	3.62	0.3767	16.6
18	$MgCO_3$	=100	96.9	3.32	0.3217	14.2
19	Limestone	=100	121.3	2.34	0.2839	12.5
20	Dolomite	=100	112.0	2.12	0.2342	10.3
21	Magnesite	=100	132.5	2.49	0.3299	14.5
	Average	=100	110.1	2.76	0.3007	13.2
Average of all treated tanks			118.1	2.17	0.2532	11.1

any carbonation of MgO was followed by the disintegration of the resultant carbonate. Therefore, during most of the first year and thereafter, the 8-ton MgO and $MgCO_3$ treatments are in effect treatments of freshly formed magnesium silicates, of simple or complex nature. The 32-ton and 100-ton MgO and $MgCO_3$ treatments, however, are in excess of the amounts which the soil was capable of disintegrating. In these cases the treatments represent MgO, probably some magnesium hydrate, basic carbonate and silicate, the latter

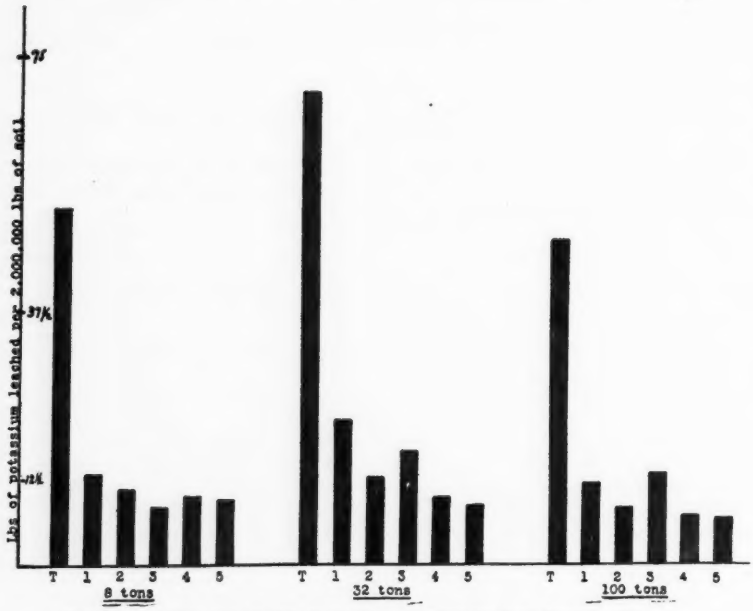

FIG. 7. PRECIPITATED $CaCO_3$ TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

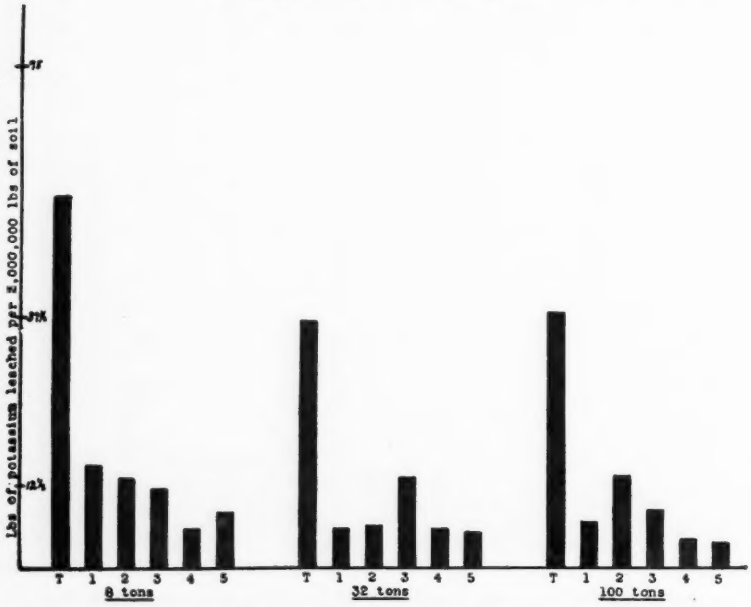

FIG. 8. PRECIPITATED $MgCO_3$ TREATMENTS, SURFACE-SOIL-ONLY TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

TABLE 6

Amounts of potassium leached from Cumberland loam, surface soil and subsoil, in field lysimeters—July, 1915, to July, 1916

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil; also wollastonite and serpentine at the rate of 32 tons

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with surface soil	Rate per 2,000,000 pounds of soil				
		tons				
22	CaO	8	121.8	2.65	0.3224	14.2
23	MgO	=8	117.5	2.65	0.3111	13.7
24	$CaCO_3$	=8	120.4	2.09	0.2518	11.1
25	$MgCO_3$	=8	114.0	2.65	0.3019	13.3
26	Limestone	=8	114.0	2.34	0.2668	10.9
27	Dolomite	=8	119.5	2.65	0.3164	14.0
28	Magnesite	=8	128.3	2.34	0.3002	13.2
	Average	=8	119.3	2.62	0.2958	12.9
29	CaO	32	108.9	3.98	0.4338	19.1
30	MgO	=32	108.0	3.98	0.4303	19.0
31	$CaCO_3$	=32	110.4	2.65	0.2923	12.9
32	$MgCO_3$	=32	109.6	2.84	0.3111	13.7
33	Limestone	=32	109.5	3.07	0.3363	14.8
34	Dolomite	=32	116.7	2.34	0.2732	12.0
35	Magnesite	=32	113.7	1.81	0.2058	9.1
	Average	=32	111.0	2.65	0.3261	14.4
36	CaO	100	121.5	2.21	0.2683	11.8
37	MgO	=100	106.5	3.32	0.3536	15.6
38	$CaCO_3$	=100	104.3	1.81	0.1887	8.3
39	$MgCO_3$	=100	93.3	3.02	0.2819	12.4
40	Limestone	=100	117.7	2.49	0.2931	12.9
41	Dolomite	=100	126.7	2.49	0.3155	13.9
42	Magnesite	=100	114.5	3.32	0.3801	16.8
	Average	=100	112.1	2.66	0.2973	13.1
43	Wollastonite	32	135.2	2.84	0.3839	16.9
44	Serpentine	32	136.5	1.99	0.2719	12.0
Average of treated tanks, except no. 43 and 44			114.1	2.64	0.3064	13.5

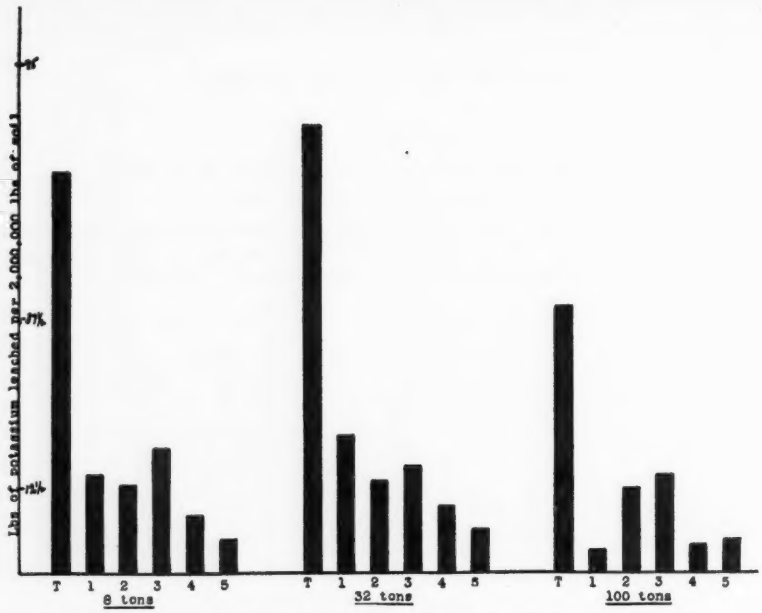

FIG. 9. PRECIPITATED $MgCO_3$ TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

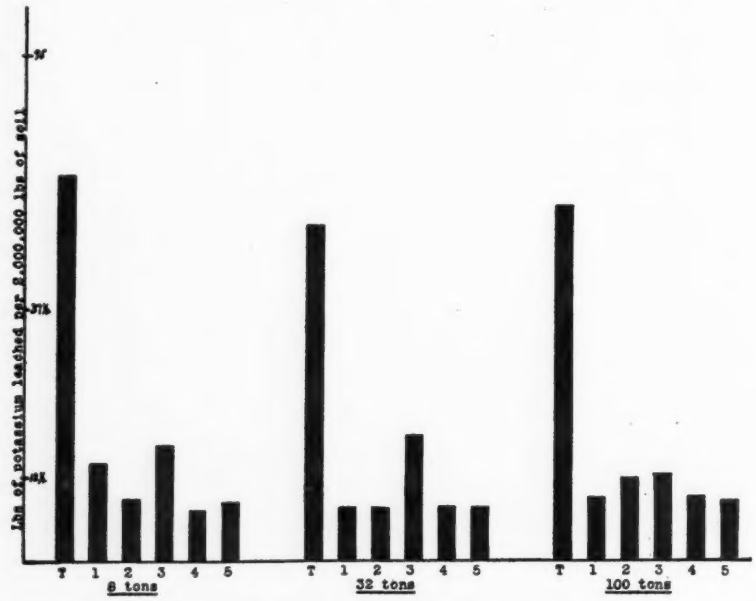

FIG. 10. 100-MESH LIMESTONE TREATMENT, SURFACE-SOIL-ONLY TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

being in excess of equivalence to the amount of calcium silicate formed by applications of lime in amounts chemically equivalent to the applied magnesia and magnesium carbonate.

Again in the second annual period, the tendency of the subsoil to yield potassium, and thereby increase the outgo passing from the surface soil, seems to have been augmented beyond any enhancement of its tendency to absorb the potassium passing downward.

Third annual period (tables 7 and 8). During the third annual period the 8-ton surface-soil tanks gave a fairly uniform outgo of potassium and an average practically identical with that of the corresponding subsoil tanks. No outstanding relationship appeared for these two sets of seven each during this period. All of the CaO had become carbonated, considerably prior to the end of the initial annual period, as was pointed out in the discussion of the second year's results from the 8-ton calcium and magnesium oxide and carbonate tanks. In this period, however, the effect of the hydrated lime is distinctly manifested in the case of the 32-ton and 100-ton tanks, in both of which treatments a large part of the applied lime had still remained in the solid hydrate phase. The third year was an exceptionally wet period and the soil was almost continuously subjected to the intense treatment of digestion with solutions of $Ca(OH)_2$. But, if we delete the data obtained from the analyses of the leachings of tanks 8 and 15, in averaging the results from the three batteries, we have 13.7 pounds as an average from the seven 8-ton surface-soil tanks, as against 16.1 pounds and 13.3 pounds, respectively, from the averages derived from leachings obtained from 6 tanks each of the 32-ton and 100-ton treatments. Excepting tanks 8 and 15, in no case has any one of the lime- or magnesia-treated tanks given an outgo of potassium equivalent to that of the blank-treatment check. There are no consistent or outstanding variations induced by the several treatments, other than the exception above noted; and, if from the average we exclude the data derived from the leachings secured from the two tanks 8 and 15, we have as an average from 19 calcic and magnesic treatments 14.3 pounds as against the 28.2 pounds outgo of the no-treatment tank.

In comparing the surface-soil tanks with the surface-subsoil tanks, we have respective averages of 13.7 pounds and 13.8 pounds for the 8-ton treatments; 16.1 pounds and 16.5 pounds, respectively, for the 32-ton tanks and 13.3 pounds and 15.6 pounds, respectively, for the 100-ton treatments, the 32-ton CaO and the 100-ton CaO tanks being omitted from the latter two averages in the case of the surface soil. Thus, in the treatments other than the two exceptions noted, the underlying subsoil has not determinably altered the potassium salt concentration of the leachings from the surface soil. However, the estopping tendency of the subsoil is distinctly manifested in the case of the 32-ton and 100-ton tanks no. 29 and 36. Assuming the same outgo of potassium from identically treated portions of surface soil with and without underlying subsoil, we find that tank 29 has fixed 31.3 pounds, the difference between 50.4 pounds (tank 8) and 19.1 pounds (tank 29). On the same assumption, the

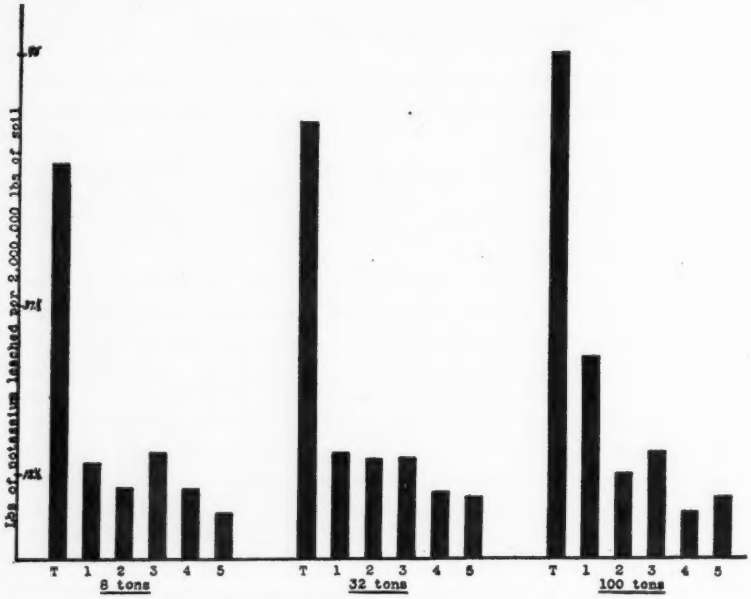

FIG. 11. 100-MESH LIMESTONE TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

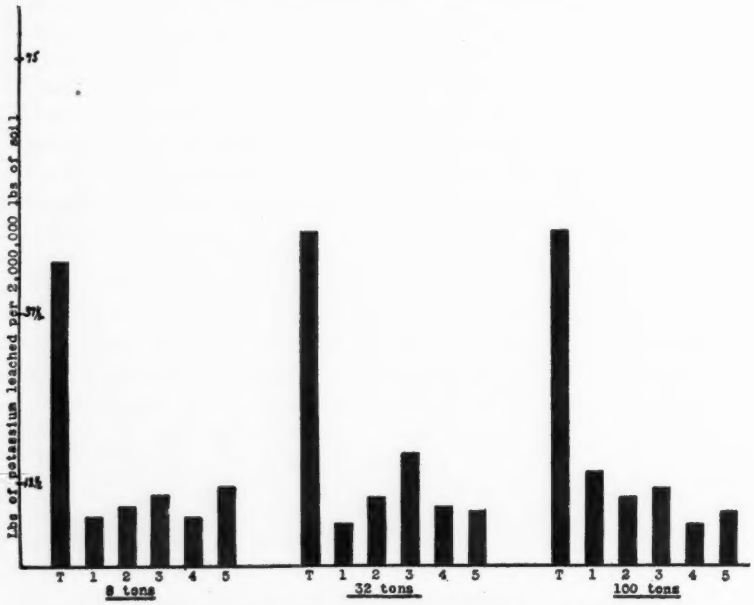

FIG. 12. 100-MESH DOLOMITE TREATMENTS, SURFACE-SOIL-ONLY TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

TABLE 7

Amounts of potassium leached from Cumberland loam, surface soil only, in field lysimeters—July, 1916, to July, 1917

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with soil	Rate per 2,000,000 pounds of soil				
		tons				
1	CaO	8	170.1	2.17	0.3691	16.3
2	MgO	=8	172.5	1.40	0.2415	10.7
3	$CaCO_3$	=8	165.6	1.71	0.2832	12.5
4	$MgCO_3$	=8	193.5	1.38	0.2670	11.8
5	Limestone	=8	180.1	2.18	0.3926	17.3
6	Dolomite	=8	139.9	1.69	0.2364	10.4
7	Magnesite	=8	185.5	2.04	0.3784	16.7
	Average	=8	172.5	1.80	0.3097	13.7
8	CaO	32	167.0	6.85	1.1439	50.4
9	MgO	=32	164.4	1.59	0.2614	11.5
10	$CaCO_3$	=32	181.6	2.35	0.4268	18.8
11	$MgCO_3$	=32	149.5	2.06	0.3080	13.6
12	Limestone	=32	185.9	2.25	0.4183	18.4
13	Dolomite	=32	175.3	2.12	0.3716	16.4
14	Magnesite	=32	197.3	2.06	0.4064	17.9
	Average	=32	174.4	2.75 2.07†	0.4738 0.3654†	21.0 (16.1)†
15	CaO	100	150.7	18.88	2.8452	125.5
16	MgO	=100	136.2	1.55	0.2111	9.3
17	$CaCO_3$	=100	163.7	2.70	0.4420	19.5
18	$MgCO_3$	=100	143.2	1.38	0.1976	8.7
19	Limestone	=100	168.8	1.74	0.2937	13.0
20	Dolomite	=100	157.3	1.65	0.2595	11.4
21	Magnesite	=100	172.4	2.33	0.4017	17.7
	Average	=100	156.0	4.32 1.89*	0.6644 0.3009*	29.3 (13.3)*
46	Blank		192.5	4.03	0.6404	28.2
Average of all treated tanks			167.6	2.96 1.39†*	0.4826 0.3245†*	21.4† (14.3)*

† Average not including tank 8, CaO 32 tons.

* Average not including tank 15, CaO 100 tons.

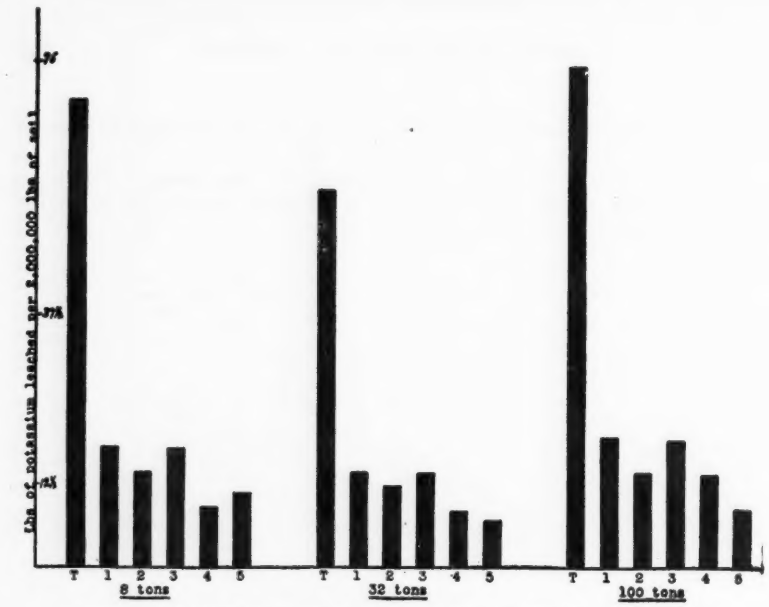

FIG. 13. 100-MESH DOLOMITE TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

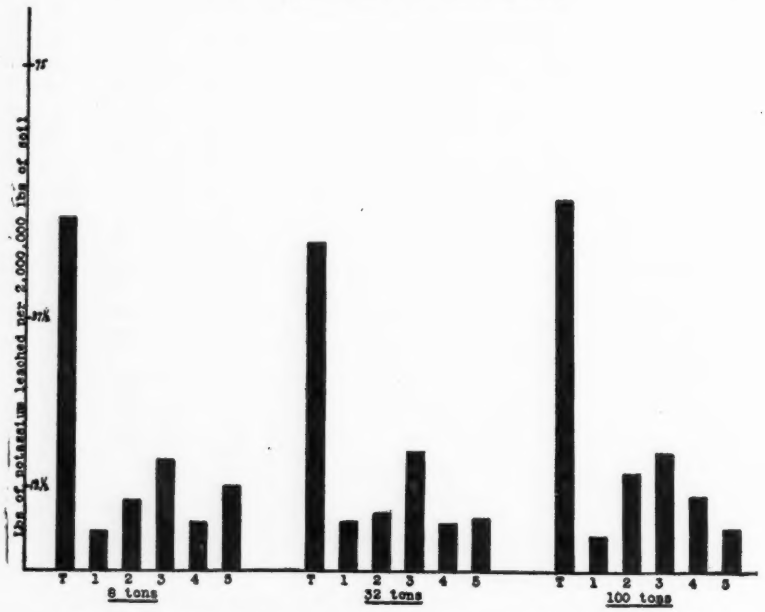

FIG. 14. 100-MESH MAGNESITE TREATMENTS, SURFACE-SOIL-ONLY TANKS CUMBERLAND LOAM
T = total; numbers refer to annual periods

TABLE 8

Amounts of potassium leached from Cumberland loam, surface soil and subsoil, in field lysimeters— July, 1916, to July, 1917

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO, at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil; also Wollastonite and Serpentine at the rate of 32 tons

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with surface soil	Rate per 2,000,000 pounds of soil				
		tons				
22	CaO	8	173.7	1.28	0.2223	9.8
23	MgO	⇔8	169.9	1.37	0.2328	10.3
24	$CaCO_3$	⇔8	180.8	1.05	0.1898	8.4
25	$MgCO_3$	⇔8	171.1	2.90	0.4202	18.5
26	Limestone	⇔8	171.3	2.14	0.3665	16.2
27	Dolomite	⇔8	173.1	2.30	0.3981	17.6
28	Magnesite	⇔8	162.4	2.22	0.3605	15.9
	Average	⇔8	171.7	1.89	0.3129	13.8
29	CaO	32	157.3	2.76	0.4341	19.1
30	MgO	⇔32	154.6	2.56	0.3958	17.5
31	$CaCO_3$	⇔32	173.1	2.19	0.3791	16.7
32	$MgCO_3$	⇔32	161.0	2.22	0.3574	15.8
33	Limestone	⇔32	163.2	2.10	0.3427	15.1
34	Dolomite	⇔32	172.7	1.85	0.3195	14.1
35	Magnesite	⇔32	186.4	2.12	0.3952	17.4
	Average	⇔32	166.9	2.26	0.3748	16.5
36	CaO	100	163.1	1.52	0.2479	10.9
37	MgO	⇔100	163.6	2.40	0.3926	17.3
38	$CaCO_3$	⇔100	165.4	1.84	0.3043	13.4
39	$MgCO_3$	⇔100	151.8	2.13	0.3233	14.3
40	Limestone	⇔100	178.0	2.05	0.3649	16.1
41	Dolomite	⇔100	179.4	2.37	0.4252	18.8
42	Magnesite	⇔100	183.1	3.14	0.4113	18.2
	Average	⇔100	169.2	2.21	0.3528	15.6
43	Wollastonite	32	189.0	4.49	0.8486	37.4
44	Serpentine	32	183.3	2.65	0.4857	21.4
45	Blank		165.5	6.40	1.0592	46.7
Average of treated tanks except no. 43 and 44.			169.3	2.12	0.3468	15.3

outgo of 125.5 pounds from tank 15 (surface soil only) has been decreased to 10.9 pounds through the absorption of potassium by the subsoil in tank 36. This is equivalent to an estoppage of 114.6 pounds for this annual period. Not only has the subsoil absorbed potassium salts, but all downward moving calcium hydroxide has also been stopped. It would be expected that the leachings from the heavily treated CaO tank would be practically saturated with $Ca(OH)_2$ many times during the period of over 5 years; however, during this period hydroxide has failed to come through the stratum of subsoil.

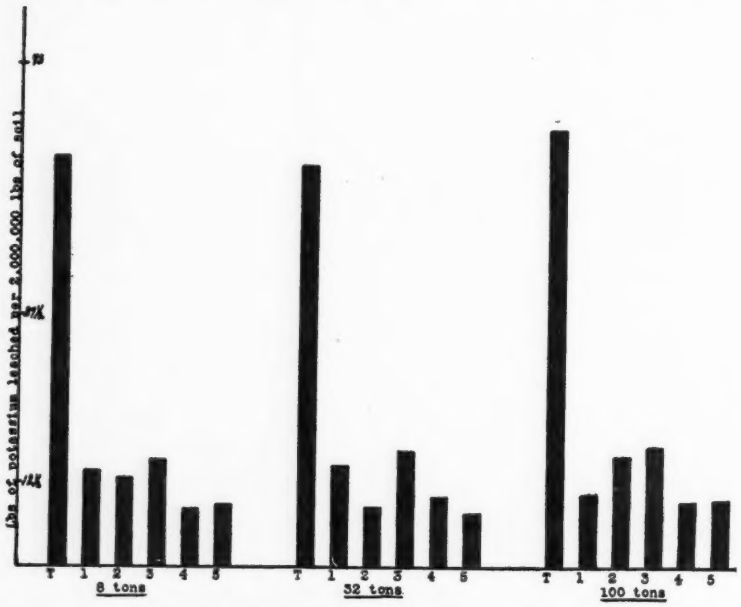

FIG. 15. 100-MESH MAGNESITE TREATMENTS, SURFACE-SOIL-SUBSOIL TANKS, CUMBERLAND LOAM
T = total; numbers refer to annual periods

Fourth annual period (*tables 9 and 10*). This annual period was very much drier than the preceding one. The restricted opportunity for hydrolysis of the potassic silicates is uniformly demonstrated for all treatments. During this year, very little, if any, hydroxide was present in tank 8, most, if not all, having undergone reversion to carbonate by July, 1917. However, considerable hydroxide still leached from the surface soil containing the 100-ton CaO treatment. The group averages of potassium leachings from the shallow tanks were 6.6 pounds, 7.6 pounds and 7.2 pounds, respectively for the 8-, 32- and 100-ton treatments, tank 15 not being included in the last average. With no. 15 included, the average of the 100-ton equivalent tanks becomes 11.2 pounds

TABLE 9

Amounts of potassium leached from Cumberland loam, surface soil only, in field lysimeters—July, 1917, to July, 1918

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with soil	Rate per 2,000,000 pounds of soil				
		tons				
1	CaO	8	81.5	1.42	0.1158	5.1
2	MgO	=8	70.9	1.88	0.1333	5.9
3	$CaCO_3$	=8	86.5	1.98	0.1713	7.6
4	$MgCO_3$	=8	89.2	1.51	0.1347	5.9
5	Limestone	=8	84.1	2.02	0.1699	7.5
6	Dolomite	=8	75.2	2.16	0.1624	7.2
7	Magnesite	=8	82.4	2.02	0.1664	7.3
	Average	=8	81.4	1.86	0.1505	6.6
8	CaO	32	71.9	2.06	0.1481	6.5
9	MgO	=32	74.3	1.80	0.1337	5.9
10	$CaCO_3$	=32	76.8	3.34	0.2565	11.3
11	$MgCO_3$	=32	74.9	1.72	0.1288	5.7
12	Limestone	=32	92.7	1.98	0.1835	8.1
13	Dolomite	=32	84.6	2.34	0.1980	8.7
14	Magnesite	=32	90.2	1.84	0.1660	7.3
	Average	=32	80.8	2.15	0.1735	7.6
15	CaO	100	45.4	17.56	0.7972	35.2
16	MgO	=100	55.4	2.54	0.1407	6.2
17	$CaCO_3$	=100	66.5	2.00	0.1330	5.9
18	$MgCO_3$	=100	54.6	1.82	0.0994	4.4
19	Limestone	=100	68.9	3.18	0.2191	9.7
20	Dolomite	=100	65.8	2.10	0.1382	6.1
21	Magnesite	=100	74.3	3.32	0.2467	10.9
	Average	=100	61.6	4.65 (2.48)*	0.2535 (0.1217)*	11.2 (7.2)*
46	Blank		109.6	3.50	0.3836	16.9
Average of all treated tanks			74.6	2.89	0.1925	8.5
Average of treated tanks, except no. 15				2.16	0.1486	7.1

* Average not including tank 15.

TABLE 10

Amounts of potassium leached from Cumberland loam, surface soil and subsoil, in field lysimeters— July, 1917, to July, 1918

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil; also wollastonite and serpentine at the rate of 32 tons

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with surface sol	Rate per 2,000,000 pounds of soil				
		tons				
22	CaO	8	89.5	1.82	0.1629	7.2
23	MgO	=8	85.3	2.98	0.2542	11.2
24	$CaCO_3$	=8	82.0	2.84	0.2329	10.3
25	$MgCO_3$	=8	84.5	1.96	0.1656	7.3
26	Limestone	=8	84.7	2.90	0.2456	10.8
27	Dolomite	=8	83.8	2.38	0.1994	8.8
28	Magnesite	=8	68.4	2.46	0.1683	7.4
	Average	=8	82.6	2.48	0.2041	9.0
29	CaO	32	75.9	3.34	0.2535	11.2
30	MgO	=32	88.6	2.54	0.2250	9.9
31	$CaCO_3$	=32	85.3	2.66	0.2269	10.0
32	$MgCO_3$	=32	102.9	2.20	0.2264	10.0
33	Limestone	=32	86.2	2.60	0.2241	9.9
34	Dolomite	=32	84.6	2.26	0.1911	8.4
35	Magnesite	=32	96.1	2.49	0.2393	10.6
	Average	= 32	88.5	2.58	0.2266	10.0
36	CaO	100	82.4	2.68	0.2208	9.7
37	MgO	=100	75.3	1.90	0.1431	6.3
38	$CaCO_3$	=100	80.2	2.16	0.1732	7.6
39	$MgCO_3$	=100	74.4	1.32	0.0982	4.3
40	Limestone	=100	88.3	1.86	0.1642	7.2
41	Dolomite	=100	82.4	3.76	0.3098	13.7
42	Magnesite	=100	94.1	2.42	0.2277	10.0
	Average	=100	82.4	2.30	0.1910	9.5
43	Wollastonite	32	89.8	2.02	0.1814	8.0
44	Serpentine	32	103.3	3.27	0.3378	14.9
45	Blank		69.2	5.28	0.3654	16.1
Average of treated tanks except no. 43 and 44			84.5	2.45	0.2072	9.5

instead of 7.2 pounds. The surface-soil tanks gave a grand average of 8.5 pounds as compared with 9.5 pounds for the surface-soil-subsoil tanks. The liberation and leaching of potassium was still evidenced in the case of the 100-ton tank no. 15, although the outgo was less than in the more humid preceding annual period. The function of the subsoil in absorbing the potassium liberated and leached from the surface soil was again manifested. The average loss of potassium from the 21 treated surface-soil tanks was only about one-half that of the blank. The same was true in the case of the comparison between the treated surface-soil-subsoil tanks and their blank. During this period, as in the preceding annual periods, the increase in the rate of treatments induced no augmentation in the potassium outgo, except in the case of burnt lime at the rate of 100 tons.

Fifth annual period (tables 11 and 12). Again in this period there is effected no consistent difference in potassium outgo to be attributed to variation in form or amount of treatment, for either the shallow or deep tanks, except once more in the case of the 100-ton CaO treatment and possibly also in the apparent parallel between the increase of $MgCO_3$ treatment and depression of potassium leachings therefrom. Here again the potassium outgo from the deep tank which received burnt lime at the rate of 100 tons per acre is decidedly less than in the case of the corresponding shallow tank. The continued tendency of both lime and magnesia treatments to effect restriction of potassium outgo is evidenced by the diminished amounts of potassium leached from the treatments, as compared with that from the untreated soil. This holds true for both depths. The analyses of both shallow and deep tank leachings for salts of calcium and magnesium demonstrate that the surface soil has yielded large amounts of the salts of these two elements to the subsoil and that the subsoil has stopped and in most cases still stops the salts yielded to it by the surface soil. Hence, it would be expected that the parallel of depressed potassium outgo and the continued occurrence of solutions of lime and magnesia salts—with their probably or possibly continued absorption by the surface soil—would have been transmitted ere this in some measure also to the subsoil.

Summary of potassium outgo data secured during the 5-year period. The results of the 5-year period are shown graphically for each annual period and for the total period in figures 1 to 15, inclusive. All the figures, except figure 2, are in the same scale. The heavy outgo of potassium from the two heavy CaO surface-soil tanks necessitated the adoption of the different scale used in this particular figure.

Considering tables 13 and 14, which embody the summation of the data obtained during the 5-year period, we find a very uniform outgo of potassium irrespective of form or amount of treatment, save only in the instances of the two heavier burnt lime treatments. The average potassium outgo from the shallow tanks is very close to that found in the case of the deep tanks.

The losses of potassium from tanks 43 and 44, which were treated with the more insoluble forms of lime and magnesia, wollastonite and serpentine, ap-

TABLE 11

Amounts of potassium leached from Cumberland loam, surface soil only, in field lysimeters—July, 1918, to July, 1919

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre 2,000,000 pounds of soil

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with surface soil	Rate per 2,000,000 pounds of soil				
		tons				
1	CaO	8	112.1	1.53	0.1715	7.6
2	MgO	=8	116.1	2.18	0.2531	11.2
3	$CaCO_3$	=8	121.3	1.57	0.1904	8.4
4	$MgCO_3$	=8	119.4	1.59	0.1898	8.4
5	Limestone	=8	118.4	1.71	0.2025	8.9
6	Dolomite	=8	115.8	2.25	0.2606	11.5
7	Magnesite	=8	118.7	2.35	0.2789	12.3
	Average	=8	116.8	1.88	0.2209	9.8
8	CaO	32	105.2	2.33	0.2451	10.8
9	MgO	=32	107.7	1.56	0.1680	7.4
10	$CaCO_3$	=32	115.9	1.52	0.1762	7.8
11	$MgCO_3$	=32	114.0	1.08	0.1231	5.4
12	Limestone	=32	127.5	1.41	0.1798	7.9
13	Dolomite	=32	116.1	1.55	0.1800	7.9
14	Magnesite	=32	120.4	1.51	0.1818	8.0
	Average	=32	115.3	1.56	0.1791	7.9
15	CaO	100	88.3	15.25	1.3466	59.4
16	MgO	=100	103.6	2.51	0.2600	11.5
17	$CaCO_3$	=100	111.5	1.66	0.1851	8.2
18	$MgCO_3$	=100	103.7	0.83	0.0861	3.8
19	Limestone	=100	114.2	1.81	0.2067	9.1
20	Dolomite	=100	110.6	1.64	0.1814	8.0
21	Magnesite	=100	116.6	1.29	0.1504	6.6
	Average	=100	106.9	3.57 (1.62)*	0.3452 (0.1783)*	15.2 (7.9)*
46	Blank		115.9	2.49	0.2886	12.7
Average of all treated tanks			113.2	2.67	0.2903	12.8
Average of treated tanks except no. 15				1.69	0.1929	8.5

* Average not including tank 15, CaO 100 tons.

TABLE 12

Amounts of potassium leached from Cumberland loam, surface soil and subsoil, in field lysimeters—July, 1918, to July, 1919

Treatments of CaO, MgO, $CaCO_3$, $MgCO_3$, 100-mesh limestone, 100-mesh dolomite and 100-mesh magnesite, each in amounts equivalent to CaO at the rates of 8 tons, 32 tons and 100 tons per acre; also wollastonite and serpentine at the rate of 32 tons

TANK NUMBER	TREATMENT		TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Material mixed with surface soil	Rate per 2,000,000 pounds of soil				
		tons				
22	CaO	8	121.3	1.45	0.1759	7.8
23	MgO	=8	116.1	1.29	0.1498	6.6
24	$CaCO_3$	=8	124.9	1.70	0.2123	9.4
25	$MgCO_3$	=8	116.2	1.04	0.1208	5.3
26	Limestone	=8	117.8	1.36	0.1602	7.1
27	Dolomite	=8	120.1	2.04	0.2450	10.8
28	Magnesite	=8	119.0*	1.75	0.2083	9.2
	Average	=8	119.3	1.52	0.1817	8.0
29	CaO	32	110.6	2.70	0.2986	13.2
30	MgO	=32	116.1	1.27	0.1474	6.5
31	$CaCO_3$	=32	119.3	1.67	0.1992	8.8
32	$MgCO_3$	=32	119.8	1.16	0.1389	6.1
33	Limestone	=32	123.5	1.73	0.2136	9.4
34	Dolomite	=32	120.5	1.36	0.1639	7.2
35	Magnesite	=32	125.3	1.42	0.1779	7.8
	Average	=32	119.3	1.61	0.1913	8.4
36	CaO	100	105.6	2.24	0.2365	10.4
37	MgO	=100	111.0	1.59	0.1765	7.8
38	$CaCO_3$	=100	121.8	1.26	0.1535	6.8
39	$MgCO_3$	=100	120.9	0.92	0.1112	4.9
40	Limestone	=100	123.1	1.64	0.2019	8.9
41	Dolomite	=100	112.9	1.69	0.1908	8.4
42	Magnesite	=100	128.9	1.83	0.2359	10.4
	Average	=100	117.7	1.60	0.1866	8.2
43	Wollastonite	32	121.8	1.97	0.2406	10.6
44	Serpentine	32	137.7	2.06	0.2836	12.5
45	Blank		130.4	3.12	0.4068	18.2
Average of treated tanks except no. 43 and 44			118.8	1.58	0.1865	8.2

* Leak sprung in outlet, average volume of tanks 26 and 27 used.

TABLE 13

Summary of potassium leaching data, Cumberland loam surface soil only, for the 5-year period, July, 1914 to July, 1919

TANK NUMBER	TREATMENT		LITRES LEACHED		PARTS PER MILLION IN SOLUTION K		GRAMS PER TANK		POUNDS FROM ACRE SURFACE 2,000,000 POUNDS OF SOIL	
	Material mixed with soil	Rate per 2,000,000 pounds of soil	Total	Average annual	Total	Average annual	Total	Average annual	Total	Average annual
		tons								
1	CaO	8	458.1	91.6	12.09	2.42	1.2761	0.2552	56.3	11.3
2	MgO	⇔8	542.6	108.5	10.86	2.17	1.0551	0.2110	48.8	9.8
3	$CaCO_3$	⇔8	564.5	112.9	14.21	2.84	1.3722	0.2744	60.6	12.1
4	$MgCO_3$	⇔8	623.1	124.6	11.15	2.23	1.2462	0.2492	55.0	11.0
5	Limestone	⇔8	593.8	118.8	12.02	2.40	1.2975	0.2595	57.3	11.5
6	Dolomite	⇔8	505.8	101.2	10.35	2.07	1.0181	0.2036	44.9	9.0
7	Magnesite	⇔8	590.6	118.2	10.06	2.01	1.1952	0.2390	52.7	10.5
	Average	⇔8	554.1	110.8	11.53	2.31	1.2086	0.2417	53.7	10.7
8	CaO	32	537.8	107.6	17.84	3.57	2.1426	0.4285	94.4	18.9
9	MgO	⇔32	529.3	105.9	8.49	1.70	0.8879	0.1776	39.1	7.8
10	$CaCO_3$	⇔32	571.8	112.4	14.21	2.84	1.5422	0.3084	68.0	13.6
11	$MgCO_3$	⇔32	494.3	98.9	8.65	1.73	0.8375	0.1675	36.9	7.4
12	Limestone	⇔32	612.4	122.5	9.36	1.87	1.1486	0.2297	50.6	10.1
13	Dolomite	⇔32	581.2	116.2	9.55	1.91	1.1144	0.2229	49.1	9.8
14	Magnesite	⇔32	627.3	125.5	8.93	1.79	1.1215	0.2243	49.4	9.9
	Average	⇔32	564.9	113.0	11.00	2.20	1.2564	0.2513	55.4	11.1

15	CaO	100	471.0	94.2	58.99	11.80	5.6661	1.1322	249.8	49.9
16	MgO	≏100	464.6	92.9	11.31	2.26	1.0026	0.2005	44.2	8.8
17	$CaCO_3$	≏100	514.3	103.5	12.36	2.47	1.2993	0.2599	57.3	11.5
18	$MgCO_3$	≏100	459.5	91.9	9.94	1.99	0.8630	0.1726	38.1	7.6
19	Limestone	≏100	555.6	111.9	11.44	2.29	1.1989	0.2398	52.9	10.6
20	Dolomite	≏100	506.7	101.3	12.77	2.55	1.1341	0.2268	49.9	10.0
21	Magnesite	≏100	567.6	113.5	11.16	2.23	1.2528	0.2506	55.2	11.0
	Average	≏100	505.6 (511.4)*	101.3 (102.5)*	18.28 (11.50)*	3.66 (2.30)*	1.7738 (1.1251)*	0.3546 (0.2250)*	78.2 (48.3)*	15.6 (9.9)*
46	Blank		418.0†	139.3†	10.02†	3.34†	1.3126†	0.4375†	57.8†	19.3†
Average of all treated tanks			541.5	108.4	13.60	2.79	1.4129	0.2909	62.4	12.5
Average of treated tanks except no. 15			545.0	109.0	11.34	2.27	1.2027	0.2360	53.1	10.6

† Average for 3 years.

* Average not including tank 15, CaO 100 tons.

TABLE 14

Summary of potassium leaching data, Cumberland loam surface soil and subsoil, for the 5-year period, July, 1914 to July, 1919

TANK NUMBER	TREATMENT		LITRES LEACHED		PARTS PER MILLION IN SOLUTION K		GRAMS PER TANK		POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL	
	Material mixed with surface soil	Rate per 2,000,000 pounds of soil	Total	Average annual	Total	Average annual	Total	Average annual	Total	Average annual
		tons								
22	CaO	8	579.5	115.9	12.68	2.54	1.2843	0.2569	56.7	11.3
23	MgO	⇔8	555.2	111.0	13.67	2.73	1.3048	0.2610	57.6	11.5
24	$CaCO_3$	⇔8	584.7	116.9	11.66	2.33	1.1918	0.2384	52.7	10.5
25	$MgCO_3$	⇔8	541.1	108.2	17.18	3.44	1.3394	0.2679	59.0	11.8
26	Limestone	⇔8	551.1	110.2	13.72	2.74	1.3544	0.2709	58.9	11.8
27	Dolomite	⇔8	563.5	112.7	15.35	3.07	1.5595	0.3119	68.9	13.8
28	Magnesite	⇔8	553.5	110.7	13.05	2.61	1.3602	0.2720	59.9	12.0
	Average	⇔8	561.2	112.4	13.90	2.78	1.3421	0.2684	59.1	11.8
29	CaO	32	525.9	105.2	17.36	3.47	1.7552	0.3510	77.4	15.5
30	MgO	⇔32	530.0	106.0	16.33	3.27	1.5734	0.3147	69.4	13.9
31	$CaCO_3$	⇔32	560.4	112.1	14.24	2.85	1.5800	0.3160	69.7	13.9
32	$MgCO_3$	⇔32	577.9	115.6	13.90	2.78	1.5803	0.3161	66.0	13.2
33	Limestone	⇔32	553.5	110.7	14.48	2.90	1.4709	9.2942	64.8	13.0
34	Dolomite	⇔32	569.7	113.9	12.09	2.42	1.2699	0.2540	55.9	11.2
35	Magnesite	⇔32	605.7	121.1	11.82	2.36	1.3536	0.2707	59.7	11.9
	Average	⇔32	560.4	112.1	14.32	2.86	1.5119	0.3024	66.1	13.2

36	CaO	100	560.1	112.0	12.93	2.59	1.3482	0.2696	59.3	11.9
37	MgO	⇨100	546.6	109.3	13.49	2.70	1.4520	0.2904	64.0	12.8
38	$CaCO_3$	⇨100	526.4	105.3	12.05	2.41	1.0921	0.2184	48.1	9.6
39	$MgCO_3$	⇨100	495.9	99.2	8.72	1.74	0.8883	0.1777	39.2	7.8
40	Limestone	⇨100	598.8	119.8	15.51	3.10	1.7089	0.3418	75.3	15.1
41	Dolomite	⇨100	581.5	116.3	15.79	3.16	1.6801	0.3360	74.1	14.8
42	Magnesite	⇨100	583.0	116.6	14.69	2.94	1.5038	0.3008	66.4	13.3
	Average	⇨100	556.0	111.2	13.31	2.66	1.3819	0.2764	60.9	12.2
43	Wollastonite	32	615.9	123.2	16.80	3.36	2.0935	0.4187	92.3	18.5
44	Serpentine	32	646.1	129.2	13.95	2.75	1.8035	0.3607	79.5	15.9
45	Blank*		365.1*	121.7	14.80*	4.93	1.8314*	0.6105	81.0*	27.0*
Average of treated tanks—except no. 43 and 44			559.2	111.9	13.84	2.77	1.4120	0.2824	62.0	12.4

* Average for 3 years only.

proach more nearly the average outgo of the checks than do the more soluble precipitated and mineral carbonates. These two deep tanks might be considered as near-blanks. However, the calcium silicate of wollastonite readily undergoes hydrolysis; but the magnesium silicate complex of serpentine is very stable. Therefore, it may be that such an intermediate result is a true indication of some, though restricted, tendency toward retardation of potassium outgo because of calcium or magnesium salts engendered by the hydrolysis of the two siliceous materials.

Disregarding, for the present, the heavy burnt lime treatments of tanks 8 and 15, the results may be considered as indicating either of two possibilities; (1) the calcic and magnesic materials may have actually depressed the tendency of the native soil potassic compounds to undergo hydrolysis; or (2) the calcic and magnesic materials may have accelerated the hydrolysis of the potassic complexes, at the same time imparting to the soil an enhanced tendency to reabsorb or readsorb such potassium salts as were liberated.

Considering the first hypothesis, we find, as is demonstrated by examination of the tank leachings data and also by the analysis of the soil atmospheres, that the larger applications of calcic and magnesic materials, including carbonates, tend to withdraw from the soil not only the CO_2 present in free soil moisture, but also large additional amounts which were, in the case of the several carbonate treatments, apparently condensed upon the surface of soil particles. A large number of periodic double titrations of the leachings from each tank have demonstrated that enough of calcium or magnesium carbonate is usually present to account for the presence of all dissolved CO_2 as being in bicarbonate formations. Thus, the bathing soil solutions become impregnated with the bicarbonates of calcium or magnesium where such carbonate treatments are given. On the other hand, we find more atmospheric CO_2 in the untreated tank than in the treated ones. We also find that the soil solution bathing the soil particles of the untreated soil is to a greater extent composed of the hypothetical acid H_2CO_3. The native soil is acid and free of determinable carbonates; however, the leachings from the blank are always alkaline to methyl orange and they are generally impregnated with determinable amounts of calcium bicarbonate, derived from the action of the carbonated water of the soil upon native calcic materials. It would therefore seem that the carbonated water, acting upon a relatively small amount of native calcic siliceous compounds, would be ordinarily unsaturated with reference to lime or magnesia, or, that it would at least become impregnated therewith much more slowly than in the case of the calcic and magnesic treatments; and that the additional uncombined carbonated water would then proceed to hydrolyze the less readily hydrolyzable potassic silicate complexes.

Thus we come to compare the activity of H_2CO_3 with the activity of CaH_2CO_3 and that of MgH_2CO_3 in effecting the hydrolysis of native potassic silicates under field exposures in the lysimeters. The results of Plummer (27) demonstrated that, under laboratory conditions, the presence of bicarbonate

of lime in water solution induced no increase in the liberation of potassium from several finely ground potassic siliceous minerals common to soils. This is in harmony with our findings.

The analyses of the periodic leachings demonstrate that any increase in the amounts of dissolved $CaCO_3$ is not accompanied by any increase in potassium outgo in the free soil-water, such as would be expected, were $CaCO_3$ solutions to effect a liberation of potassium.

Furthermore, the relative activities of the bicarbonates of calcium and magnesium throw some light upon the question. The solubility of $MgCO_3$, as the bicarbonate in carbonated water solutions, is many times that of calcium carbonate in the same solvent, under conditions of normal temperature and pressure. However, although the amounts of the two alkali-earth carbonates applied were of chemical equivalence, there proved to be a wide disparity between the lime-absorption and the magnesia-absorption co-efficients of this soil. This disparity resulted in the rapid absorption and disappearance of the 8-ton-CaO-equivalent treatments of $MgCO_3$, although the major portion of the equivalent $CaCO_3$ application remained as such; so that the comparison between the effects of CaH_2CO_3 and MgH_2CO_3 will be considered as referring more particularly to the two heavier treatments. The active mass of the magnesium bicarbonate solution is much greater than the active mass offered by the calcium carbonate within a given period; hence, were the bicarbonate of lime to effect liberation of potassium, the bicarbonate of magnesium would be expected to accomplish still greater liberation. But, we find the reverse to be true. The magnesium carbonate treatments have appeared to depress the outgo of potassium salts to an even greater extent than did the treatments of calcium carbonate. Yet, the magnesium carbonate treatments have yielded such concentrated free soil-water solutions of magnesium bicarbonate, that these treatments have been the first to satisfy the absorptive properties of the subsoil and the first to yield concentrated leachings through the subsoil; this, too in spite of the large amount of magnesia absorbed by the soil, as compared with the distinctly smaller amounts of lime absorbed from chemically equivalent amounts of $CaCO_3$. This extensive absorption has taken place directly and without any liberation or exchange of potash. Thus we find that free H_2CO_3 will effect the maximum liberation of potassium to the free-soil water leachings; that the smaller amounts of calcium dissolved in the H_2CO_3 will show some depression in the solvent action and that the larger amounts of magnesium dissolved in the H_2CO_3 will effect a still further depression.

The work of Parker (25) demonstrated that, by the addition of a hydrate solution, the neutralization of acid as it is engendered by the absorption of the strong base from a practically undissociated neutral salt will preclude the evidence of liberation of potassium from the native siliceous materials. In like manner, after the absorption of calcium from a heavy treatment of its carbonate forms, followed by the liberation of the CO_2, this liberated gas will, with water and the excess of $CaCO_3$, form a nearly neutral salt which would be

expected to be less active than the free hypothetical acid H_2CO_3. While this would be true of heavy calcic treatments, the reverse would apply in the case of light treatments. For, were all of the added $CaCO_3$ to undergo absorption and disintegration, the liberated CO_2 would to some extent enrich the free soil-water and afford a stronger H_2CO_3 solution. However, this concentration of H_2CO_3 is in turn reduced by the reversal of the reaction induced by the hydrolysis of the newly formed absorption compounds of calcium. Furthermore, the analyses of leachings and soil atmospheres of the tanks indicated a selective condensation of CO_2, which inhibits any extensive outgo of CO_2 dissolved in the low-calcium content free water of the light treatment or no-treatment tanks. But, in the presence of excessive amounts of the more soluble carbonate forms, particularly magnesium carbonate, such condensed CO_2 will readily combine with the carbonate and with it come from the soil in the bicarbonate combinations.

In the light of such data, it would seem reasonable and logical to deduce that the dissolving of calcium and magnesium carbonate by the carbonated soil-water has depressed the solvent action of the soil-water thus impregnated; i.e., the application of the precipitated and native mineral carbonates has depressed the amounts of potassium yielded to the free soil-water through any hydrolytic disintegration of the native silicates containing potassium.

Nevertheless, on the other hand, *we have the second hypothesis* whereby it is assumed that actual liberation of water-soluble potassium has resulted from additions of calcic and magnesic compounds, but that such treatment has likewise enhanced the absorptive tendency of the soil, thus permitting reabsorption or readsorption of the supposedly liberated potassium. The tendency of soils to absorb potassium from neutral potassic salts is well known. The extent of absorption of the cation and liberation of the anion is dependent, in part, upon the degree of dissociation of the dissolved neutral salt. However, following such absorption, we find a tendency toward attainment of a dynamic equilibrium, which results in a subsequent augmentation in the amounts of soluble or extractable potassium to be found in the free soil-water.

Shreiner and Failyer (30), in demonstrating the absorption of potassium from neutral salts, also show the tendency toward subsequent release of the absorbed potassium to leaching. Initially, the leachings were of maximum potassium salt concentration, decreasing to a near-constant. However, save for the exception noted, CaO at the rates of 32 tons and 100 tons, our lysimeter leachings from the large number of precipitated and native mineral carbonates do not evidence any diffusion of soil-surface concentrates of potassic salts to the free soil-water, such as would be anticipated had there occurred an enrichment of soluble potassium salts in the soil-particle surface film, through the phenomenon of interchange of bases. On the other hand, the eventual increased outgo of potassium—the exceptions which transpired in the case of the heavy burnt lime treatments of tanks 8 and 15—is in conformity with the above-cited demonstrations of the delayed tendency of liberated potassium salts to

enter free soil-water solution, upon being subjected to leaching. According to Shreiner and Failyer (30) "the absorbed potassium, like the absorbed phosphate, is continually diffusing into the free soil-moisture and becoming, therefore, directly accessible to plants." As a matter of fact, not only did all of the chemical and mineral carbonates induce a diminished leaching of potassium, but the 8-ton CaO treatments, which speedily reverted to the carbonate, also failed to show any increase, but rather a decrease of potassium outgo during the 5-year period; while *the hydrate still present in the 32-ton and 100-ton treatments showed no indication of liberation of potassium until the third and humid year.*

In advancing the second hypothesis, that of reabsorption of any liberated potassium, it might be contended that the liberation of potassium actually found in the two heavy CaO surface-soil tanks was due to a coincidental granulation of the soil of such nature as to preclude reabsorption; while, in the case of the other treatments of calcic and magnesic compounds, potassium liberation was effected without parallel granulation and vitiation of the soil's powers of absorption. But, since the physical change of soil structure induced by the 32-ton and 100-ton burnt-lime treatments was immediate, while the release of increased amounts of potassium to leachings was deferred for over two years, it seems more reasonable to conclude that the disintegration of potassic complexes was induced solely by the burnt lime treatments and by them only under conditions involving intense treatment and long-continued contact. The intensity of treatment found to be requisite to register potassium liberation is of such magnitude as to be well beyond the bounds of practical consideration. Because of the foregoing data, and their relationship to the cited findings of Shreiner and Failyer (30) and those of Plummer (27), we may attribute to the several carbonate treatments an actual depression of hydrolysis and liberation of native soil potassium, rather than any release of potassium through basic exchange.

One further possibility suggests itself. It might be assumed that the chemical and mineral carbonates effected an actual chemical disintegration of the native potassic silicates and that there was induced a resultant absorption of such a nature as to withstand any tendency toward diffusion to the free soil-water derived from natural precipitation; but, that the reabsorbed potassium would, nevertheless, yield to the more intensive activities of plant roots enough potassium to appreciably enhance the supply that would have been obtained without the alkali-earth treatments. Assuming, however, that the plant root-system of a wheat crop would be sufficiently extensive to derive such a hypothetical benefit, the above offered supposition would be invalidated by the previously cited wheat-ash analyses offered by Gaither (12), and by the writer (20). Furthermore, the averages of the annual analyses of corn, oats, wheat, and grass offered by Lyon and Bizzell (18) show that the potassium content of these crops is uninfluenced by applications of 3000 pounds of burnt lime per acre; and that the potash content of those crops is independent of the

amounts of potassium leached, although the plants elaborated about twice as much potassium as was lost from the soils by leaching.

Certain unpublished data were secured by Prof. C. A. Mooers from carefully controlled plat experiments, at the Tennessee station, with the same acid Cumberland loam as that which was placed in the tanks. These data afford an opportunity for observations relative to the dependence to be placed upon lime, as an indirect source of potassium for growing plants. The experiments involve a continuous cowpea-wheat rotation, one crop each of cowpeas and wheat being harvested each year. At the beginning of the experiment and again after a period of 12 years, one ton of burnt lime per acre was applied to certain of the plats, all of which received annual applications of phosphate, both with and without potash. After several years, both crops manifested a distinct need of potassium in the check plats and also in those plats which received phosphate, both with and without lime. The annual applications of phosphate, of course, carried some $CaSO_4$ and the 1-ton application of burnt lime was annually supplemented with calcium to that extent. The second application of burnt lime, like the first, did not correct this distinct need of potassium. On the other hand, an annual application of manure, at the rate of 4 tons per acre, maintained the yields of both crops and prevented any physiological evidence of potassium deficiency. The incorporation of the organic matter of the manure would be followed of course by the formation of large amounts of CO_2 and the enrichment of the soil solution in this product of oxidation. Assuming the potassium content of the manure to be insufficient to offset the insufficiency of potassium registered by both crops, this, in conformity with the lysimeter results, tends to demonstrate that a free soil-water solution of the hypothetical acid H_2CO_3 is more active in the liberation of native soil potassium as a nutrient to the plant, than is the carbonic acid solution of the bicarbonate salt. Following the application of lime or magnesia in their several forms, such occurrences of CaH_2CO_3 or MgH_2CO_3 in the soil-water would be increased, with the strongly indicated tendency toward decreased extraction of potassium. Furthermore, analyses of some of the earlier crops of wheat, which were harvested before the applied lime had been greatly diminished by leaching and through removal of cowpeas and wheat, indicated rather forcibly that the use of lime had appreciably depressed the potassium content of the wheat straw.

The potassium in leachings from the 22 lime-magnesia-sulfur tanks of Cherokee sandy loam during the initial two years

The results contained in tables 15 and 16, and summarized in table 17, are from the Cherokee sandy loam, over a 2-year period of exposure. The annual and aggregate amounts of potassium leached are shown graphically in figures 11 to 19, inclusive. This Cherokee sandy loam is a reddish-brown soil and carries considerable clay. Its total potassium content and that portion soluble

in each N/5 HNO_3 and HCl (Sp. g., 1.115), are given in table 2. The supplementary experiment with this soil was intended primarily as an adjunct to certain observations made in a preliminary report by the writer and associates (22) on the influence of various forms of lime and magnesia upon the outgo of native sulfur as sulfates. This series of tanks, however, embraces a number which have received sulfur in several forms, both with and without lime or magnesia. Since the function of the subsoil was so well demonstrated in the system of 46 tanks, all of the 22 additional tanks were filled with the surface soil only. The series was comprised as follows: one blank and the following no-sulfur single CaO and MgO treatments per 2,000,000 pounds of soil; one receiving 2000 pounds of CaO; one 3750 pounds of CaO; one receiving MgO chemically equivalent to 2000 pounds of CaO; one MgO chemically equivalent to 3750 pounds of CaO; one ground limestone, and one ground dolomite, both of 100-mesh fineness, and each chemically equivalent to 2000 pounds of CaO. Five tanks received sulfur as $FeSO_4$, at the equivalent rate of 1000 pounds of sulfur per acre 2,000,000 pounds of soil. One of these five sulfate tanks received no additional treatments; one an additional treatment of 3750 pounds of CaO; another an additional application of MgO equivalent to CaO at the rate of 3750 pounds; while the remaining two received, in one case, CaO at the rate of 32 tons and in the other case MgO at the rate chemically equivalent to 32 tons of CaO. In like manner, each tank of another set of five tanks received iron pyrites in an amount furnishing sulfur at the rate of 1000 pounds per 2,000,000 pounds of soil. As in the case of the five sulfate tanks, one received no alkali-earth treatment, while the remaining four were treated singly with the four respective applications of CaO and MgO at the two rates. In still another set of five tanks, powdered sulfur was added to each tank at the rate of 1000 pounds per 2,000,000 pounds of soil. In this set, one tank received sulfur alone, while one each of the other four received CaO or MgO at the two rates. The CaO at the rate of 3750 pounds per 2,000,000 pounds of soil and its chemical equivalence of MgO used in one pair of the checks and in two tanks of each sulfur-treated set, represented an application of 2000 pounds of CaO or its MgO equivalence, plus 1750 pounds of CaO, or its MgO equivalence; the plus treatment representing the amount required to neutralize the immediate acidity of the ferrous sulfate or the potential acidity to be accredited to the unoxidized pyrites and elemental sulfur, in case the latter two materials should undergo complete oxidation. Therefore, of the five tanks which received $FeSO_4$, with and without lime or magnesia, the four receiving CaO and MgO may be considered as involving treatments of varying amounts of $CaSO_4$ or $MgSO_4$. The reaction of the leachings have demonstrated the absence of $FeSO_4$, therefrom, even in the case of the check; and the leachings have been alkaline to methyl orange without exception, though the original soil was acid in character. As in the case of the 46 lysimeters embracing Cumberland loam, all of the treatments were mixed throughout the 8-inch depth of moist soil, equivalent in each case to 100 pounds of moisture-free soil. The

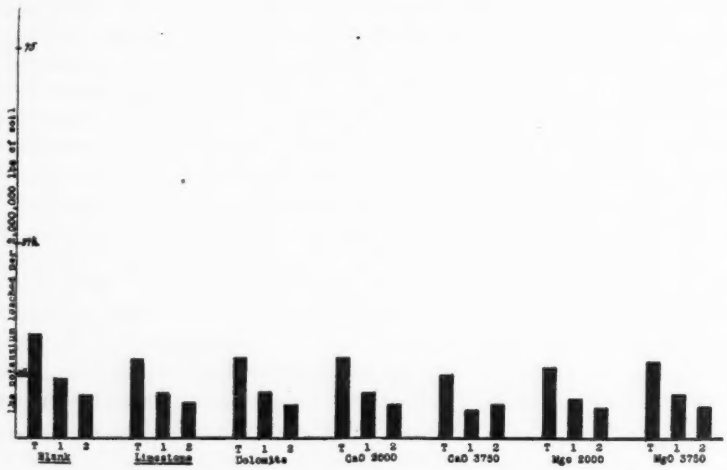

FIG. 16. BLANKS AND CHECKS; CHEROKEE SANDY LOAM, SURFACE SOIL ONLY
T = total; numbers refer to annual periods

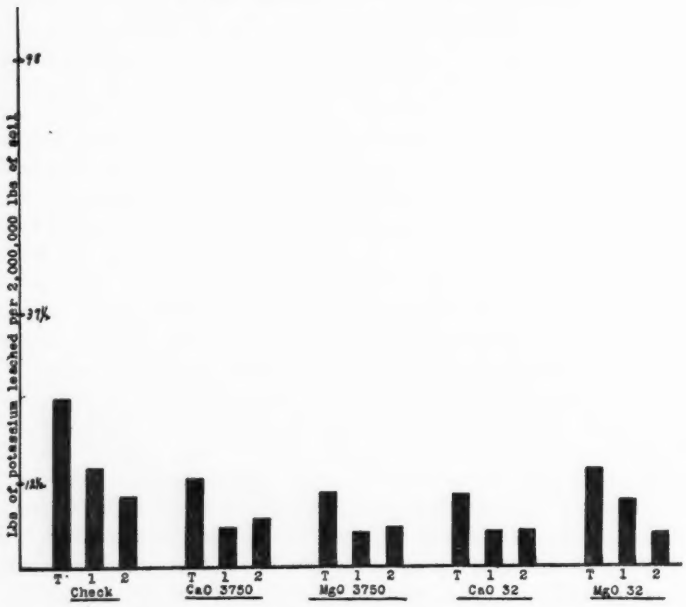

FIG. 17. SULFUR TREATMENTS, $FeSO_4$ = 1000 POUNDS SULFUR PER 2,000,000 POUNDS CHEROKEE SANDY LOAM, SURFACE SOIL ONLY
T = total; numbers refer to annual periods

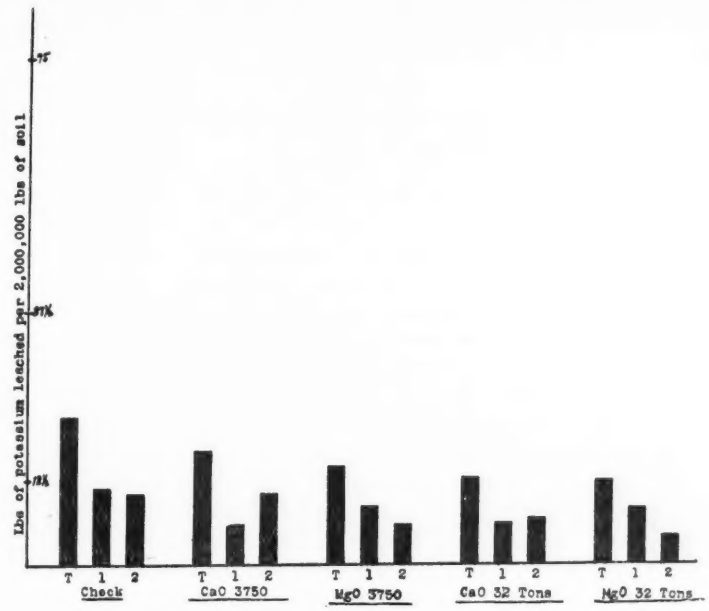

FIG. 18. SULFUR TREATMENTS, IRON PYRITES=1000 POUNDS SULFUR PER 2,000,000 POUNDS CHEROKEE SANDY LOAM, SURFACE SOIL ONLY
T=total; numbers refer to annual periods

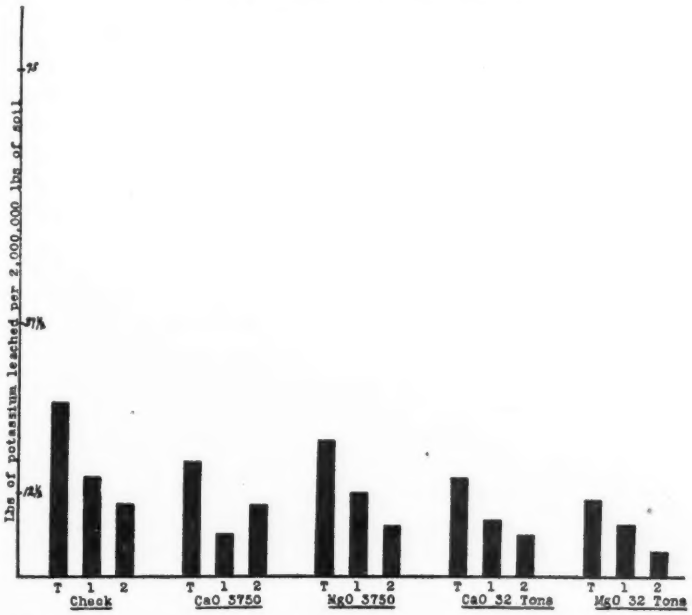

FIG. 19. SULFUR TREATMENTS, 1000 POUNDS PER 2,000,000 POUNDS CHEROKEE SANDY LOAM, SURFACE SOIL ONLY
T=total; numbers refer to annual periods

data from the 22-tank lime-magnesia-sulfur series cover the initial 2-year period after installation on August 3, 1917.

First annual period. In considering first the data of table 15, we find that the average outgo of potassium from the no-sulfur lime and magnesia treated tanks amounted to 7.9 pounds as compared with 11.8 pounds for the blank during the initial year. In no case did a single light lime, magnesia, limestone, or dolomite treatment increase the leaching of potassium.

In the group of five $FeSO_4$ tanks, only the tank receiving the sulfate alone yielded as much potassium to the leachings as was carried through in the leachings from the blank. The $FeSO_4$ treatment might well be considered a treatment of H_2SO_4. However, as previously pointed out, the ferrous sulfate treatments were neutralized by the added CaO and MgO and, apparently, even by the native alkali or alkali-earth siliceous compounds of the soil. Examination of the leachings demonstrated that no free acid or $FeSO_4$ came through, most of the outgoing SO_4 having been in combination with calcium. This observation is interesting in its relationship to the observation of Ruprecht (28), who stated ". . . . . it was found that marked amounts of soluble aluminum and iron salts were removed from the plats receiving sulfate of ammonium, by long-continued washing of the soils with distilled water . . . . ." Even if all of the applied and mixed acid iron sulfate was not neutralized by the added or native alkali or alkali-earth compounds, none was yielded to the natural leachings consequent to rainfall. If the increase in potassium outgo from the $FeSO_4$ check, above that yielded by the blank, is considered as actually representing an increased decomposition of native soil potassic compounds, it would be difficult to determine whether the release is to be attributed to direct action of the acid radical, or to a subsequent basic exchange after the formation of $CaSO_4$. An actual depression in solvent action appears to have been registered in the case of both the light lime and light magnesia treatments and also the heavy lime treatment, which represents an excessive hydrated-lime treatment, plus $CaSO_4$.

Again, in the case of the group of five iron pyrites tanks, we find a distinct retardation in the potassium outgo for each lime and each magnesia addition. The iron pyrites check is practically identical with the blank. Sulfate determinations on the leachings from this pyrites check demonstrated that oxidation of the pyrites to $FeSO_4$ had occurred to an appreciable extent. With the increased SO_4 outgo, there was found a parallel increase in the outgo of calcium. Hence, this treatment might be considered as a partial treatment of $CaSO_4$.

In the third, or sulfur, group we find an average potassium outgo of 10.2 pounds for the initial year, as compared with 11.8 pounds for the blank. The sulfur check, however, has yielded more of potassium than has the blank; while the light application of MgO has also induced a yield somewhat greater than that derived from the untreated tank. As in the case of the pyrites check, analyses of leachings demonstrated that, in the case of both blank and

TABLE 15

Amounts of potassium leached from Cherokee sandy loam surface soil in field lysimeters—August, 1917, to August, 1918

Treatments of limestone, dolomite and oxides of calcium and magnesium, the oxides having also supplementary treatments of sulfur in the forms of ferrous sulfate, iron pyrites or elemental sulfur

TANK NUMBER	TREATMENT				TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Alkali earth		Sulfur					
	Form applied	Amount per 2,000,000 pounds of soil	Form applied	Amount of sulfur per 2,000,000 pounds of soil				
				lbs.				
50	None	None	None	None	85.7	3.11	0.2665	11.8
51	Limestone	⇨2000 lbs. CaO	None	None	85.1	2.40	0.2042	9.0
52	Dolomite	⇨2000 lbs. CaO	None	None	85.3	1.96	0.1672	7.4
53	CaO	2000 lbs.	None	None	84.6	2.46	0.2081	9.2
54	CaO	3750 lbs.	None	None	76.2	1.68	0.1280	5.6
55	MgO	⇨2000 lbs. CaO	None	None	79.3	2.21	0.1752	7.7
56	MgO	⇨3750 lbs. CaO	None	None	75.6	2.56	0.1933	8.5
	Average...				84.4	2.21	0.1793	7.9
57	None	None	$FeSO_4$	1000	75.2	4.45	0.3346	14.8
58	CaO	3750 lbs.	$FeSO_4$	1000	73.8	1.84	0.1358	6.0
59	MgO	⇨3750 lbs. CaO	$FeSO_4$	1000	71.5	1.69	0.1208	5.3
60	CaO	32 tons	$FeSO_4$	1000	76.7	1.58	0.1228	5.4
61	MgO	⇨32 tons CaO	$FeSO_4$	1000	54.9	4.25	0.2333	10.3
	Average...				70.4	2.76	0.1895	8.4
62	None	None	Iron pyrites	1000	83.7	3.15	0.2637	11.6
63	CaO	3750 lbs.	Iron pyrites	1000	77.3	1.92	0.1484	6.5
64	MgO	⇨3750 lbs. CaO	Iron pyrites	1000	79.7	2.44	0.1945	8.7
65	CaO	32 tons	Iron pyrites	1000	90.0	1.62	0.1458	6.4
66	MgO	⇨32 tons CaO	Iron pyrites	1000	82.1	2.26	0.1855	8.2
	Average...				82.6	2.28	0.1876	8.3
67	None	None	Sulfur	1000	81.6	4.20	0.3427	15.1
68	CaO	3750 lbs.	Sulfur	1000	73.7	2.04	0.1503	6.6
69	MgO	⇨3750 lbs. CaO	Sulfur	1000	79.4	1.74	0.2885	12.7
70	CaO	32 tons	Sulfur	1000	88.5	2.16	0.1912	8.4
71	MgO	⇨32 tons CaO	Sulfur	1000	58.3	3.10	0.1807	8.0
	Average...				76.3	2.65	0.2307	10.2

all treatments, a considerable amount of sulfur had been converted to sulfates. In the blank, the outgo of sulfate has been accounted for principally as calcium sulfate; so that this tank represents a progressive treatment of light amounts of $CaSO_4$. Likewise, the four CaO and MgO tanks have in effect received supplementary and progressive additions of either $CaSO_4$ or $MgSO_4$.

Taken as a whole, we find that the six lime, magnesia, limestone or dolomite treatments effected a depressing influence on the outgo of potassium, where no supplementary sulfur materials were applied; that eleven of the twelve lime or magnesia treatments, with supplementary sulfur in three forms, yielded less of potassium than did the blank; and that, of the three tanks receiving the sulfur materials without lime or magnesia, one was practically identical with the blank, while the other two gave slight increase in potassium leachings. It must, therefore, be concluded that neither light nor heavy applications of burnt lime or burnt magnesia gave any evidence of liberation of native soil potassium during the initial annual period of the experiment with the Cherokee sandy loam. This accords with the initial annual-period results, obtained in the case of the Cumberland loam, where the indication of potassium liberation appeared first in the third annual period.

Second annual period. In comparing the 8.4-pound potassium yield from the blank tank no. 50 with the leachings from the limestone-, dolomite-, and oxide-treated tanks no. 51 to 56 (table 16), we find for the six treated tanks an average outgo of 6.4 pounds from consistent results, indicating that the calcic and magnesic treatments have to some extent actually depressed the outgo of potassium.

However, in the case of tank 57, receiving $FeSO_4$ alone, we find a slight tendency toward the enrichment of the potassium content of the leachings. But, where the $FeSO_4$ has been supplemented by additions of CaO or MgO in tanks 58 to 61, the depressive tendency of the oxides is again manifested.

In tanks 62 and 63, receiving respectively iron pyrites and iron pyrites plus the light application of lime, there is a small increase in the potassium outgo. The remaining three tanks, no. 64, 65 and 66 of this set, show the same tendency toward diminished potassium leachings that was noted in the case of the $FeSO_4$ group.

Considering next the sulfur tanks no. 67 to 71, we find that the continued oxidation of sulfur has resulted in considerable increase in the potassium yielded by the soil to the leachings from the tank which received sulfur alone. The light application of burnt lime effected a marked depression in the outgo of potassium salts, when compared to the check sulfur tank, although a small increase is to be noted when the comparison is made with the blank tank no. 50. A repetition in the depression of potassium outgo occurred in the case of the MgO tanks no. 69 and 71 and also in the case of the CaO tank no. 70. A consistent and marked decrease is noted in the case of tank 71 and tanks 61 and 66, corresponding treatments, with reference to MgO, though differing in the form of the added sulfur.

TABLE 16

Amounts of potassium leached from Cherokee sandy loam surface soil in field lysimeters—August, 1918, to August, 1919

Treatments of limestone, dolomite and oxides of calcium and magnesium, the oxides having also supplementary treatments of sulfur in the forms of ferrous sulfate, iron pyrites or elemental sulfur

TANK NUMBER	TREATMENT				TOTAL LITRES LEACHED	PARTS PER MILLION IN SOLUTION K	GRAMS PER TANK	POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL
	Alkali earth		Sulfur					
	Form applied	Amount per 2,000,000 pounds of soil	Form applied	Amount of sulfur per 2,000,000 pounds of soil				
				lbs.				
50	None	None	None	None	131.6	1.45	0.1908	8.4
51	Limestone	⇨2000 lbs. CaO	None	None	130.5	1.21	0.1579	7.0
52	Dolomite	⇨2000 lbs. CaO	None	None	130.9	1.04	0.1361	5.5
53	CaO	2000 lbs.	None	None	131.1	1.16	0.1521	6.7
54	CaO	3750 lbs.	None	None	122.3	1.27	0.1553	6.8
55	MgO	⇨2000 lbs. CaO	None	None	124.4	1.11	0.1381	6.1
56	MgO	⇨3750 lbs. CaO	None	None	124.9	1.15	0.1436	6.3
	Average...				127.4	1.16	0.1472	6.4
57	None	None	$FeSO_4$	1000	124.3	1.87	0.2324	10.2
58	CaO	3750 lbs.	$FeSO_4$	1000	121.7	1.36	0.1655	7.3
59	MgO	⇨3750 lbs. CaO	$FeSO_4$	1000	118.0	1.10	0.1298	5.7
60	CaO	32 tons	$FeSO_4$	1000	109.4	1.10	0.1203	5.3
61	MgO	⇨32 tons CaO	$FeSO_4$	1000	102.2	0.98	0.1002	4.4
	Average...				115.1	1.28	0.1496	6.6
62	None	None	Iron pyrites	1000	124.4	1.93	0.2401	10.6
63	CaO	3750 lbs.	Iron pyrites	1000	126.6	1.93	0.2443	10.8
64	MgO	⇨3750 lbs. CaO	Iron pyrites	1000	128.2	1.06	0.1359	6.0
65	CaO	32 tons	Iron pyrites	1000	132.0	1.20	0.1584	7.0
66	MgO	⇨32 tons CaO	Iron pyrites	1000	117.4	0.88	0.1033	4.6
	Average...				125.7	1.40	0.1764	7.8
67	None	None	Sulfur	1000	130.7	1.93	0.2522	11.1
68	CaO	3750 lbs.	Sulfur	1000	122.7	1.98	0.2429	10.7
69	MgO	⇨3750 lbs. CaO	Sulfur	1000	123.5	1.42	0.1754	7.7
70	CaO	32 tons	Sulfur	1000	122.9	1.20	0.1475	6.5
71	MgO	⇨32 tons CaO	Sulfur	1000	102.6	0.77	0.0790	3.5
	Average...				120.5	1.46	0.1794	7.9

TABLE 17

Summary of potassium leaching data, Cherokee loam, surface soil only, for the 2-year period ending August 4, 1919

TANK NUMBER	TREATMENT				LITRES LEACHED		PARTS PER MILLION IN SOLUTION K		GRAMS PER TANK		POUNDS PER ACRE SURFACE 2,000,000 POUNDS OF SOIL	
	Alkali earth		Sulfur									
	Form applied	Amount per 2,000,000 pounds of soil	Form applied	Amount per 2,000,000 pounds of soil	Total	Average annual	Total	Average annual	Total	Average annual	Total	Average annual
				lbs.								
50	None.....	None	None	None	217.3	108.7	4.58	2.29	0.4573	0.2287	20.2	10.1
51	Limestone.....	⇨2000 lbs. CaO	None	None	215.6	107.8	3.61	1.81	0.3621	0.1811	16.0	8.0
52	Dolomite.....	⇨2000 lbs. CaO	None	None	216.2	108.1	3.00	1.50	0.3033	0.1517	19.6	9.8
53	CaO.....	2000 lbs.	None	None	215.7	107.9	3.62	1.81	0.3602	0.1801	15.9	8.0
54	CaO.....	3750 lbs.	None	None	198.5	99.3	2.95	1.48	0.2833	0.1417	12.4	6.2
55	MgO.....	⇨2000 lbs. CaO	None	None	203.7	101.9	3.32	1.66	0.3133	0.1567	13.8	6.9
56	MgO.....	⇨3750 lbs. CaO	None	None	200.5	100.3	3.71	1.86	0.3369	0.1685	14.8	7.4
	Average.....				208.4	104.2	3.37	1.69	0.3265	0.1633	15.4	7.7
57	None.....	None	$FeSO_4$	1000	199.5	99.8	6.32	3.16	0.5670	0.2835	25.0	12.5
58	CaO.....	3750 lbs.	$FeSO_4$	1000	195.5	97.8	3.20	1.60	0.3013	0.1507	13.3	6.7
59	MgO.....	⇨3750 lbs. CaO	$FeSO_4$	1000	189.5	94.8	2.79	1.40	0.2506	0.1253	11.0	5.5
60	CaO.....	32 tons	$FeSO_4$	1000	186.1	93.1	2.68	1.34	0.2431	0.1216	10.7	5.4
61	MgO.....	⇨32 tons CaO	$FeSO_4$	1000	157.1	78.6	5.23	2.62	0.3335	0.1668	14.7	7.4
	Average.....				185.5	92.8	4.04	2.02	0.3391	0.1695	14.9	7.5

62	None.....	None	Iron pyrites	1000	208.1	104.1	5.08	2.54	0.5038	0.2519	22.2	11.1
63	CaO.....	3750 lbs.	Iron pyrites	1000	203.9	102.0	3.85	1.93	0.3927	0.1964	17.3	8.7
64	MgO.....	⇨3750 lbs.CaO	Iron pyrites	1000	207.9	104.0	3.50	1.75	0.3304	0.1652	14.7	7.4
65	CaO.....	32 tons	Iron pyrites	1000	222.0	111.0	2.82	1.41	0.3042	0.1521	13.4	6.7
66	MgO.....	⇨32 tons CaO	Iron pyrites	1000	189.5	94.8	3.14	1.57	0.2888	0.1444	12.8	6.4
	Average.....				206.3	103.2	3.68	1.84	0.3640	0.1820	16.1	8.1
67	None.....	None	Sulfur	1000	212.3	106.2	6.13	3.07	0.5949	0.2975	26.2	13.1
68	CaO.....	3750 lbs.	Sulfur	1000	196.4	98.2	4.02	2.01	0.3932	0.1966	17.3	8.7
69	MgO.....	⇨3750 lbs. CaO	Sulfur	1000	202.9	101.5	3.16	1.58	0.4639	0.2320	20.4	10.2
70	CaO.....	32 tons	Sulfur	1000	211.4	105.7	3.36	1.68	0.3387	0.1694	14.9	7.5
71	MgO.....	⇨32 tons CaO	Sulfur	1000	160.9	80.5	3.87	1.94	0.2597	0.1299	11.5	5.8
	Average.....				196.8	98.4	4.11	2.06	0.4121	0.2051	18.1	9.1

Aggregate of potassium leached during 2-year period. When we compare the respective averages of the limestone, dolomite, CaO or MgO treatments for the 2-year period (table 17) we find that in no one case, of the 18 tanks which received calcic or magnesic materials, has there been indicated any interchange of calcium or magnesium for the native soil potassium. Rather, there has been indicated for the 2-year period a distinct diminution in the amount of potassium leached, where additions of the alkali-earthy materials have been made.

As noted in the discussion of the 5-year period results from the Cumberland loam soil, there has ensued as a result of both lime and magnesia treatments, either a depression of potassium liberation, or else an enhancement in the retentive properties of the soils for any potassium possibly liberated. Following the line of reasoning mentioned previously in quoting the work of Shreiner and Failyer (30), it would appear that had such liberation of potassium resulted from treatments of lime and magnesia, any immediate tendency to reabsorb the liberated potassium would be mitigated by the ultimate tendency toward attainment of equilibrium between the absorbed potassium-enriched surface film and the free water of the soil. Hence, as in the case of the preceding studies with the Cumberland loam soil, the Cherokee sandy loam results indicate that when either lime or magnesia is added to a long-leached residual soil there occurs an actual depression in the concentration of potassium salt in the free soil water, rather than a liberation of potassium, with consequent enhanced supplies of potassic salts available to the roots of growing plants. However, it may again be pointed out that an extensive plant root development might be expected to secure potassium compounds more readily from any liberated and reabsorbed potassium than from the potassium compounds in their natural condition. Nevertheless, assuming an interchange between calcium or magnesium and native soil potassium, and assuming wheat to be a representative crop, the results of Gaither (12) and those of MacIntire (19) previously cited, would indicate no such activity on the part of the plant, where every opportunity was afforded for such assumed potassium liberation. The same obtains in the case of the plant-ash results for corn, oats, wheat, and grass, as reported by Lyon and Bizzell (18).

PRACTICAL VALUE OF RESULTS

In summarizing the 5-year-period results from the Cumberland loam and the 2-year-period results from the Cherokee sandy loam, in their application to and interpretation into practice, it would seem that one definite and positive conclusion is justified, with reference to these two types of soil under the prevailing climatic conditions, to wit: ***practical or economical applications of burnt calcareous limestone, burnt dolomitic limestone, ground calcareous limestone, or ground dolomitic limestone will not effect a direct chemical liberation of native soil potassium.***

Some indication of potassium liberation was obtained where $CaSO_4$ was engendered from sulfureous materials incorporated with the Cherokee sandy loam, in the absence of supplementary lime treatments. However, with this particular soil, the meagerness of the indicated liberation, as compared with the intensity of treatment, was such as to minimize the dependence to be placed upon economical amounts of calcium sulfate fertilizers as liberants of soil potassium in amounts sufficient to be of practical value. This, however, is without prejudice with reference to the need for, or value of, the sulfur content of such materials.

However, the probable fixation of nitrogen; improved tilth, particularly through increase in the amounts of more active organic matter; enhanced biological activation and other cumulative benefits resulting from the judicious use of lime or limestone may be expected to effectuate such a marked general improvement in the plant feeding zone as to accelerate the hydrolysis of potassic silicates and diffusion of soluble potassium salts to the roots of the growing plants. Such secondary benefits might be fully equivalent, in their liberative action, to that which would be possible were chemical substitution of calcium for potassium actually accomplished.

SUMMARY AND CONCLUSIONS

It is pointed out that deductions from laboratory studies have led to the assumption that lime may be considered as a liberant of native soil potassium, to the extent of benefiting plant growth.

Review of the literature indicates that such an assumption is not justified in the case of the forms of lime used in practice, with the possible exception of calcium sulfate.

Analytical data from the Pennsylvania station demonstrated that, after long usage, burnt lime and ground limestone caused a marked depression in the potassium content of wheat straw.

The obscurely recorded analytical results obtained upon the K_2O analysis of the limed plats of the Pennsylvania station are quoted *in toto*. The fact is pointed out, that the error of sampling such large areas is a factor to be considered, and that a comparison based on the results from the upper two 7-inch zones supports different conclusions from those that would be drawn from a consideration of the three 7-inch zones.

The Cumberland loam lysimeter experiments, embracing 46 tanks, with and without subsoil, and receiving varying amounts of nine different forms of lime and magnesia are considered with reference to the total potassium leached during each of five annual periods.

During the initial annual period, the deep tanks gave a greater average outgo of potassium than did the shallow, surface-soil tanks. The subsoil tanks were more uniform in their yield of potassium than were those of the surface soil. No increase of potassium outgo occured coincident with increase in the amount of treatment.

The same observations hold for the results of the second year. During the third and very humid annual period, the heavier applications of burnt lime began to show a marked effect in the liberation of potassium from the surface soil. The potassium liberated to the free soil-water was absorbed by the subsoil. The averages of the results induced by the other treatments show a marked uniformity within each series, as well as a close parallel between the outgo from the surface-soil tanks (excluding the 32-ton and 100-ton CaO treatments) and that from those containing both surface soil and subsoil. The individual and average amounts passing from all treatments were considerably less than those obtained from the no-treatment tanks.

The amounts of potassium leached during the relatively dry fourth annual period were distinctly smaller than were those yielded during the preceding year, the subsoil tanks again giving somewhat higher results. The 32-ton CaO surface-soil tank returned to normal, coincidently with the disappearance of $Ca(OH)_2$ from the soil. The 100-ton burnt lime surface-soil tank still yielded an excessive outgo of potassium, as compared with the other oxide and carbonate treatments. Both surface-soil and surface-soil-subsoil tank blanks again yielded more potassium to the leachings than did any single treatment (other than CaO, 100 tons), or the average of treatments.

The fifth annual period registered the liberative action of the 100-ton CaO treatment and the subsequent absorption of the liberated potassium by the subsoil. Again, each calcic and magnesic treatment at each rate (excepting the 100-ton CaO treatment) has depressed the potassium content of leachings, as compared with the blanks of both surface-soil and surface-soil-subsoil tanks.

The summation of the data of the 5-year period indicates that the magnesic compounds exert a somewhat more depressive influence on the outgo of potassium salts, than do the corresponding lime compounds, though no great differences are manifest. Excepting, after the second year, tanks 8 and 15, which still contained residual $Ca(OH)_2$ from heavy applications of burnt lime, all of the calcic and magnesic treatments have yielded smaller amounts of potassium to the leachings than were yielded by the no-treatment tanks. The extent of outgo of potassium appears to have been uninfluenced by the intensity or magnitude of the applications of carbonate forms. Excepting the burnt lime tanks, the several treatments show a relatively close concordance within each of the two systems of different depths. However, the subsoil tanks demonstrated closer concordance, and an average outgo greater than that from the surface tanks.

It is pointed out that CO_2 solutions in H_2O are apparently more active upon native soil potassic complexes than is the same hypothetical acid, when it is in part neutralized by the formation of acid carbonates of calcium or magnesium.

When considered in connection with the cited plat results and plant-ash analyses, the data of the 46-tank series demonstrate that it is not tenable to assume that native soil potassium is liberated from the silicate forms to the free soil-water by ordinary applications of the oxides, or the several carbonates of cal-

cium or magnesium, in light or heavy amounts. Nor does it appear probable that potassium is released from siliceous combination and furnished to the film water, there to be concentrated and held by physical absorption against the tendency to diffuse to the more dilute free soil-water. Rather, it would appear that, were liming to induce any enhancement in the amounts of potassium elaborated by the plants, such an effect would be the result of accelerated plant growth, thereby causing greater range and more vigorous root action and root decay, which are calculated to extract more potassium from the native stores of potassium, unaltered by any lime or magnesia treatments in reasonable amounts.

Thirty-two-ton and 100-ton treatments only have given any indication of potassium liberation; and such liberated potassium has, in time, diffused to the natural leachings. This tends to emphasize the fact that, in all other cases, the diminished potassium leachings were actually due to a lesser solvent action of the free soil-water, when it became impregnated with calcium or magnesium bicarbonates. For, had the other forms effected any potassium liberation, dynamic tendencies would have resulted in an ultimate enrichment of the potassium content of their free-water solutions.

Reference is made to the plats of the Tennessee station which show that burnt lime, in 1-ton applications, has failed to rectify the definite need of potassium manifested in crops of cowpeas and wheat, in a rotation composed exclusively of these two crops.

The 22 lysimeters containing Cherokee sandy loam afford an opportunity to study the effect of single light applications of burnt lime, burnt magnesia, limestone and dolomite upon the outgo of potassium. They also furnish opportunity for observations upon the potassium-liberating tendencies of calcium and magnesium sulfate engendered from $FeSO_4$, iron pyrites, or sulfur, when these three materials are used alone and together with light and heavy applications of CaO or MgO.

During the initial annual period, each unsupplemented form of lime and magnesia depressed the outgo of potassium, while each lime and magnesia treatment supplemented by $FeSO_4$, iron pyrites or sulfur produced the same effect, with one exception.

The results of the second annual period demonstrate a continued depressive effect on potassium outgo as a result of single treatments of lime, magnesia, limestone, or dolomite. The same tendency is manifested in 10 of the 15 treatments where CaO and MgO singly were supplemented by $CaSO_4$ or $MgSO_4$, formed or engendered within the soil, from the treatments of $FeSO_4$, iron pyrites or sulfur. The distinct depressive tendency of heavy applications of MgO, even when augmented by engendered $MgSO_4$, was particularly consistent.

The average of the two year's potassium outgo from the Cherokee soil shows a distinct depressive action induced by CaO, MgO or limestone when applied separately and alone; and the same result likewise for lime and magnesia when used in connection with $FeSO_4$, iron pyrites or sulfur. The three sulfur compounds when used alone gave, in each case, a slightly greater yield

of potassium; but, it is not clear whether this was due to direct action of the engendered acid, or to substitutive action of the calcium and magnesium sulfates formed therefrom within the soil.

Again, as in the case of the Cumberland loam, even the 32-ton application of burnt lime failed to register any increase in the potassium yielded to the outgoing free soil-water during the first two years after treatment.

The results from these two residual soils demonstrate that the original free soil-water leachings are richer in potassium salts than they are when they become impregnated, in slight or excessive degree, with calcium or magnesium bicarbonate derived from any one of the several forms of these two alkali-earths. Furthermore, excepting, in the case of the Cumberland loam, the excessive and impractical 32-ton and 100-ton CaO treatments, nothing that has been developed would suggest the possibility that the lime, magnesia or their several chemical or mineral carbonate treatments have so altered the original form of soil potassium as to render any residual portion of it more available or beneficial to plant growth.

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PLATE 1

FIG. 1. GENERAL VIEW OF HILLSIDE SYSTEM USED FOR EXPOSURE AND LEACHING EXPERIMENTS

FIG. 2. INSIDE VIEW OF HILLSIDE SYSTEM USED FOR EXPOSURE AND LEACHING EXPERIMENTS

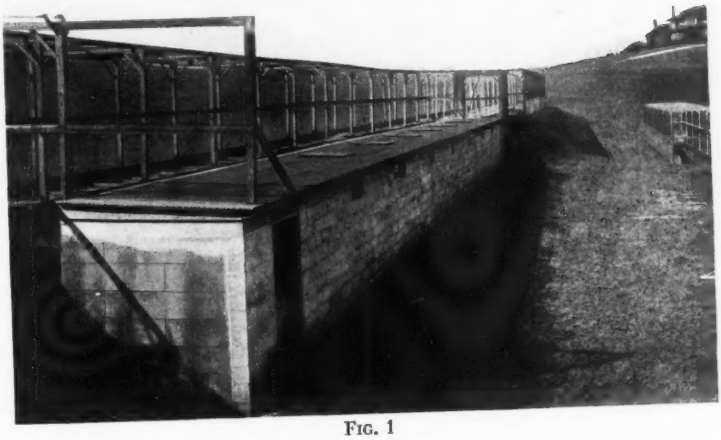

FIG. 1

FIG. 2

INFLUENCE OF SODIUM CHLORIDE UPON THE PHYSIOLOGICAL CHANGES OF LIVING TREES

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Various observations in the neighborhood of factories, salt refineries and salt mines seem to have led to the general belief that sodium chloride always has a harmful effect on plants and trees. Our knowledge of the rôle of chlorine and sodium in plant growth is very limited. Only recently an attempt has been made to study more fully the influence of sodium chloride upon plant growth.

REVIEW OF LITERATURE

The literature on the subject of fertilization with common salt presents considerable evidence that often an increase in yield may be expected, but a number of investigators report failures with the use of salt for certain agricultural crops. Agriculturists in different countries have been using sodium chloride to a certain extent, but the beneficial effects were often ascribed to the sodium-ion only, due perhaps to the view that sodium might replace potassium. In recent years, however, several investigators take the viewpoint that the chlorine-ion might have a direct fertilizing value, or an indirect fertilizing value by the acceleration of certain processes. An indirect result might be caused by the increase of acidity in certain soils, which would make certain plant-food constituents more available.

Effect on exterior form

Studies made by a number of investigators of the effect of the physiological changes on the exterior form of plants, caused by applications of sodium chloride, often show marked responses. Dassonville (8) observed that the morphological characters of *Lupinus albus* under the influence of different salts were greatly modified. Hansteen (12) found that wheat plants grown in cultural solutions containing chlorides produced larger roots and shorter leaves than when grown in solutions containing other salts. Marked changes in the leaf structure and the transpiring power of wheat have been observed by Harter (14). Saline soils containing 1, 1.5 and 2 per cent of total salts, of which 0.7, 1 and 1.4 per cent were NaCl (70 per cent), were diluted with garden loam on the basis of dry weight. The mixed soils were then placed

in containers sealed with paraffine to make comparative transpiration measurements by weighing possible. Plants of wheat, oats and barley grown from seeds in these saline soils very soon developed a pronounced waxy bloom on the leaf surface and a thickening of the cuticule occurred. The thickness of the cuticule increased with the concentration of the soil. The size of the epidermal cells decreased as the concentration of the salt in the soil increased, the cells of the plants grown on the non-saline soils being the largest. Leaves of wheat detached from plants grown in non-saline soils on which the bloom was not conspicuous, lose by transpiration two to three times as much moisture as leaves from plants grown in soil containing 1 per cent of sodium chloride. Nobbe and Siegert (24, 25) reported a higher transpiration in buckwheat plants grown in water cultures containing NaCl. Investigations made by Laurent (20) with sugar beets and carrots in connection with the plant-food supply in its relation and variation in plants, showed that NaCl in soil had the effect of lengthening both carrots and beets, but reduced the diameter of these plant roots. Buckwheat grown to maturity in water cultures by Tottingham (32) showed that the length of roots and the production of dry matter in leaf blades was depressed in solutions containing an addition of NaCl. Sugar beets when grown in the greenhouse were more watery where chlorides were applied, and the yield of the dry matter was greatly increased. Van Hecke (17) conducting experiments with salt to prevent the gummosis of fruit trees, treated the trees with salt, giving 1, 2 and 3 pounds per tree, and found at the end of the season that the tree receiving 3 pounds did not suffer from gummosis, while the ones receiving 1 and 2 pounds were slightly injured by the decrease. The other untreated trees were severely injured, lost most of their branches and bore but little fruit. The effect of salt water on cultivated plants is reported by Wohltmann (35). If the amount of salt was from 5 to 10 gm. per liter of solution the growth of the better grasses and leguminous plants was dwarfed and the yield reduced. Common salt used as top-dressing on oats in the manurial experiments carried on by the Agricultural Society of Scotland (38), gave satisfactory results against lodging, but the effect of top-dressing with salt on barley reported by the Board of Agricultural Education in Great Britain (36, 37) was to cause the barley to lodge rather than to stiffen the straw.

Effect on chemical composition

Physiological changes influencing the chemical composition of plants have been reported in a great number of cases. Hartwell and Wessels (16) found that the per cent of phosphorus in crops treated with salt as a fertilizer was increased. Studying the influence of chlorine compounds in crude Stassfurt salts upon the composition of potatoes, Sjollema (28) found that the effect of the chlorine salts was to lower the starch content. Süchting (31) came to the same conclusions, while Tottingham (32) found that by an application of

sodium chloride alone the composition of the potato tubers was only slightly altered, but the quality was seriously affected. According to Bolin (5, 6) the dry matter per hectare is not less with NaCl. De Ruijter de Wildt et al (9) found that although the yield of beets was high with an application of 300 kgm. NaCl per hectare, the salt content of the soil had changed their composition, reducing the sugar content, changed the relation of potassium and sodium by greatly increasing the sodium content and also increased the content of chlorine and of ash. Micheels (23) studying the effect on germination, length of leaf, length of root and weight of wheat plantlets grown in solutions of NaCl and KCl, reports that the chlorine-ion was harmful, decreasing the lengths of root-hairs and of leaf, and depressing the weight of the plants. Nobbe (25), giving data on ash analyses for buckwheat, points out that the per cent of ash in roots was increased by sodium chloride. Comparing garden plants with his culture plants the increase was from 6.8 to 15.3 per cent for roots and from 8.7 to 18.6 per cent for stems. Prinsen Geerlings (27) who made a study of the influence of sodium salts in the soil upon the composition of sugar cane, found that an application of either NaCl, $CaCl_2$ or $MgCl_2$ to the soil caused an increase in potash in the ash of the cane.

Toxic effects of sodium chloride

It seems that a number of investigators hold the view that sodium chloride, even in small amounts, is not only harmful but also dangerous to plant life. Still Hugo de Vries (33) pointed out already in an early study that it is "a wrong viewpoint however widely held, that strong salt solutions (for example a sodium chloride solution of 10 to 20 per cent) are dangerous for the life of plant cells." Harter (15), who made extensive comparisons of his own results with those of other investigators relative to the growth of wheat seedlings in salt solutions, concluded that sodium chloride in a concentration of about 300 parts per million, is not toxic to these plants. Guthrie and Helms (11), working with pot cultures to determine the limits of endurance of different farm crops to injurious substances, found that a salt solution of 0.05 per cent prevented germination of wheat by only 0.2 per cent, of corn by 0.25 per cent and of rye by 0.2 per cent. The growth was affected to a still lesser degree. Hendry (18) using 13 varieties of legumes in pure quartz sand with NaCl of 0.04, 0.16, 0.3, 0.5 and 1 per cent of the dry weight of the sand, found that as a general rule the germination was retarded, the height of the plants was lessened, the blossoming period changed, a reduction in number and size of the leaves was caused, and finally premature death resulted. Birger (3), however, studying the influence of sea-water upon the germination of seeds, placed 27 species of Scandinavian seeds for a period of 30 days in sea-water containing 3.4 per cent of salt, and found that although the vitality of a number of species was destroyed, the vitality of others was little or not at all affected. In some instances he found that the number of seeds which ger-

minated was increased by having been in the sea-water for 30 days as compared with dry seeds. By the extensive investigations on the effects of chlorides in alkali soils of Utah, Harris (13) found sodium chloride the most toxic of a number of common chlorides. He found that at a concentration of 0.2 per cent sodium chloride in the soil, the germination of wheat was reduced by 50 per cent.

EXPERIMENTS

In a cut-over swampy soil on the College Farm at New Brunswick, N. J., a number of selected tree stumps, which has been allowed to grow for 5, 6 or more years, were treated with common rock salt. One hundred and thirty stumps of as nearly equal size as could be found were selected, including white oak, black oak, birch, maple, and a few chestnut, dogwood and

TABLE 1

Chosen tree stumps treated with common rock salt in 1919

NUMBERS	APPROXIMATE AVERAGE HEIGHT	SALT APPLIED PER TREE	VARIETY OF TREE			
			Oak	Birch	Maple	Chestnut, etc.
	feet	*pounds*				
1 to 10	11	1	2	2	5	1
11 to 20	12	2	3	2	2	3
21 to 30	13	3	4	2	1	3
31 to 40	13	4	7	2		1
41 to 50	13½	5	3	4	3	
51 to 60	12	6	7	1	1	1
61 to 70	13½	7	7	1	2	
71 to 80	13	8	6	1	2	1
81 to 90	14	9	8	1		1
91 to 100	14	10	5	1	3	1
101 to 130	14	None	14	6	5	5
Total			66	23	24	17

cherry. The trees were treated in the manner given in table 1. The stumps were surrounded by a large number of tree stumps, which could also be used to collaborate the results. Only thirty trees not treated with salt, however, were under constant observation.

Analyses made of the rock salt used, show from 96 to 98 per cent sodium chloride, very little magnesium chloride and some impurities.

The salt was applied in a dry state, on top of and around the stumps. The application was made during the days of April 3, 4 and 5, 1919. The weather was sunny and dry, but soon after the application heavy rains partly dissolved the salt. It was not until far along in the summer that all of the salt was dissolved where the heavier applications were made.

A general examination on May 14 showed that some birch trees which were given the greater amount of salt (above no. 60) were already injured, the

TABLE 2

Condition of tree stumps four months after the treating with common rock salt

NUMBER OF TREE STUMP	VARIETY	APPROXIMATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		feet	*pounds*	
1	Birch	12	1	Healthy appearance
2	Oak	9	1	Healthy appearance
3	Maple	12	1	Slight yellowish tint in most of the leaves
4	Maple	7	1	Healthy appearance
5	Maple	15	1	Vigorous growth, leaves large
6	Maple	8	1	Leaves yellowish tinted
7	Maple	8	1	Healthy appearance
8	Birch	15	1	Healthy
9	Oak	12	1	Healthy
10	Dogwood	10	1	Healthy
11	Dogwood	10	2	Healthy
12	Oak	12	2	Healthy
13	Birch	18	2	Vigorous growth; leaves dark green
14	Chestnut	12	2	Injured; leaves curling, yellowish
15	Chestnut	11	2	Healthy; vigorous growth
16	Maple	10	2	Healthy
17	Birch	20	2	Vigorous growth; leaves extremely large and shiny; dark
18	Oak	16	2	Vigorous growth
19	Maple	6	2	Seriously injured; leaves curling; brown at the edges
20	Oak	15	2	Healthy; broad, shiny leaves
21	Oak	10	3	Healthy; bluish-green, large leaves
22	Oak	10	3	Bluish colored, large leaves
23	Oak	11	3	Healthy; bluish-green, large leaves
24	Chestnut	7	3	Injured; all leaves dropped except leaves of top shoots
25	Maple	8	3	Injured; leaves at the top of the branches dead; leaves only one third of normal size
26	Birch	13	3	Slightly injured; leaves brown at the tips and somewhat at the edges
27	Birch	18	3	Healthy
28	Cherry	17	3	Healthy
29	Walnut	10	3	Healthy
30	Oak	8	3	Healthy; leaves shiny; bluish color
31	Birch	18	4	Healthy; thrifty
32	Oak	15	4	Slightly injured; leaves brown at the edges and slight change in tint of color towards yellow
33	Oak	8	4	Injured; leaves brown, curled
34	Cherry	10	4	Injured; leaves curled; sickly appearance
35	Oak	12	4	Thrifty; large leaves
36	Oak	15	4	Main stem healthy; side stems injured; leaves curling with brown edges
37	Oak	13	4	Healthy
38	Oak	9	4	Healthy; head veins of leaves have a slightly yellowish tint

TABLE 2—*Continued*

NUMBER OF TREE STUMP	VARIETY	APPROXIMATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		feet	*pounds*	
39	Oak	17	4	Healthy; bluish-green leaves; thrifty
40	Birch	18	4	Sickly appearance; leaves large, yellowish in color; catkins have a peculiar conical shape (plate 4)
41	Oak	12	5	Healthy
42	Birch	15	5	Older leaves small and sickly; second-growth shoots are large and shiny; catkins conical shape
43	Birch	15	5	Top shoots dead; leaves brown and curling; catkins deficient in vigor
44	Birch	12	5	Healthy; head veins of leaves slightly yellow; no catkins
45	Birch	18	5	Healthy; catkins conical
46	Maple	13	5	Old leaves small and sickly in appearance; new shoots with thrifty large leaves
47	Oak	18	5	Healthy
48	Maple	14	5	Leaves partly curled as if there was lack of moisture; sickly appearance
49	Oak	13	5	Healthy
50	Maple	8	5	Leaves which are left curled; sick appearance; partly dead
51	Oak	12	6	Healthy
52	Birch	14	6	Dead; small new shoots died also
53	Oak	10	6	Partly injured; main stem thrifty; injured leaves brownish and curling
54	Sumach	10	6	Sickly appearance; leaves drooping
55	Oak	18	6	Healthy; second growth shoots have large leaves
56	Oak	10	6	Healthy, with large leaves
57	Oak	12	6	Healthy
58	Oak	12	6	Healthy
59	Maple	8	6	Dead
60	Oak	15	6	Healthy with bluish-green, shiny leaves
61	Oak	18	7	Healthy with bluish-green but small leaves
62	Oak	12	7	Injured; leaves brown and curling
63	Oak	13	7	Healthy
64	Oak	18	7	Leaves large; bluish in color, shiny; vigorous growth in new top shoots; leaves of tall main stem (18 feet) much larger than leaves of side stems (8 to 9 feet), which are slightly injured; leaves of side stems spotted with small yellow blotches; part of leaves curling
65	Oak	15	7	Healthy; veins on the back of the leaves a little yellow
66	Birch	12	7	Dead
67	Oak	15	7	Partly injured; leaves brownish in color
68	Oak	12	7	Partly injured; leaves on main stem healthy

TABLE 2—*Continued*

NUMBER OF TREE STUMP	VARIETY	APPROXIMATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		feet	*pounds*	
69	Maple	8	7	Injured; leaves dropped; making second growth but leaves tiny and curled, clustering around the stem; size of new leaves from one-tenth to three-tenths of normal size; these small clustered leaves wither after a short time
70	Maple	10	7	Seriously injured; only a few leaves (top) of highest branches left, these brown and curled
71	Oak	10	8	Injured; all leaves brownish; lower leaves of branches dropping, remainder had a sick appearance; curling
72	Birch	13	8	Dead
73	Oak	14	8	Slightly injured; leaves brownish in color
74	Oak	17	8	Partly injured; leaves with brown edges
75	Oak	13	8	Injured; leaves yellow; sickly appearance; curling
76	Oak	15	8	Veins on the back of the leaves yellow; developing later into spotted leaves
77	Cherry	13	8	Injured; leaves yellowish
78	Oak	18	8	A number of leaves brown, dried; some with only brown edges
79	Maple	10	8	All leaves dropped and very small new shoots formed which dried out later
80	Maple	10	8	All stems dead, but a few small new shoots starting from roots
81	Oak	12	9	Slightly injured; second growth extremely vigorous
82	Chestnut	18	9	Seriously injured; all leaves brown and curling
83	Oak	13	9	Injured; sickly appearance. (A birch standing nearby killed by the same dose)
84	Oak	12	9	Partly injured; most of the leaves look sickly, with a shiny brown surface
85	Oak	11	9	Injured; brownish leaves, curling at the edges
86	Oak	16	9	Seriously injured; highest leaves of top shoots dropped and remainder brown and sickly
87	Oak	16	9	Yellow tint on all leaves
88	Oak	15	9	Injured; leaves brownish with a rubber-like consistency
89	Birch	15	9	Seriously injured; only few leaves at the end of the highest shoots left. (A maple standing nearby also badly injured by the same dose)
90	Oak	18	9	Partly injured; leaves of the shorter stems brown and curled; those of the higher stems, however, very large
91	Oak	18	10	All veins on the back of the leaves yellowish, giving the appearance of lace-work

TABLE 2—*Concluded*

NUMBER OF TREE STUMP	VARIETY	APPROXIMATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		feet	*pounds*	
92	Oak	12	10	Injured; sickly appearance; leaves having a mass of local discolorations, starting at the extreme end of the small veins and gradually increasing; after some time leaves become dry, but have a rubber-like consistency; difficult to break or tear these leaves
93	Oak	12	10	Part of the leaves brown and curled
94	Maple	8	10	All leaves that are left are brown and curled
95	Birch	15	10	Most of stems dead; a few seriously injured and one apparently healthy; small new shoots from roots
96	Maple	12	10	Dead
97	Ash	10	10	Dead, except two small new shoots starting from the roots
98	Oak	17	10	Slightly injured; only few leaves curled and brownish
99	Maple	12	10	No leaves of the first growth left, but a few tiny shoots of the second growth appearing; these small shoots dried out
100	Oak	15	10	Sickly appearance like no. 92; only end-leaves of branches left; all leaves near stems dropped, giving the stems the appearance of a tree in the late autumn, when a few leaves are still left before heavy frost
101–130	Oaks, Maples, Birches, Chestnuts, etc.		None None None None	All trees healthy throughout the entire season except two of the chestnut trees, which were sick; their leaves being brownish and curling toward the end of the season

young leaves having a withered appearance. The salt was at this time not yet completely dissolved under these injured trees. On June 7 the birch trees which showed injury at the earlier date were making new sprouts; long before the second growth of the control birch trees started. The treated oaks appeared at this time more thrifty than the untreated, having a much darker green foliage. An examination on June 15 showed that some maple and birch trees which received the larger application were dying. Some of the oaks with the same application were injured; the leaves getting brown edges and slightly curling. Those with smaller amounts had an entirely different appearance. Here the salt seemed to act as a fertilizer, producing broad, heavy, dark bluish-green leaves.

An individual examination was made on August 7, at the height of the season. The results are given in table 2.

DISCUSSION

The physiological influence of sodium chloride upon the different species of trees is by no means the same. The susceptibility to injury differs greatly not only for the different species, but also within the same species. Individuals, often standing close to each other, and apparently growing under the same circumstances—as far as moisture, weather conditions and soil type go—react so differently that it is difficult to say where the injury of a certain amount of salt starts and where the stimulating or beneficial effect stops. This is especially true for the hardy oak woods. The soft-wood trees are much more easily injured. However, the range of injury for maple and birch is also rather wide. A small application of salt acts apparently as a fertilizer for oak trees. Some trees make even a vigorous growth with an application of 7 pounds of sodium chloride. In some cases injury occurs when 4 pounds are applied. In the case of birch trees slight injury is recorded by an application of 3 pounds. The range for birch trees, of a height of approximately 15 to 18 feet, between stimulation and injury seems to be approximately 2 to 3 pounds. The maple, which grows fast and consequently takes up moisture more rapidly for transpiration of food materials, etc., is affected by as little as 1 or 2 pounds of salt.

As a rule the stimulating or fertilizing effect results in longer shoots and larger leaves which have often a darker green color than the leaves of untreated trees. The surface of these leaves is shiny, sometimes having a waxy consistency. The larger the leaves are, the darker green is their color, and the more glossy is their surface. With oak trees the leaves are not only extremely large, but also a greater number have developed. This gives the leaves the effect of a very luxuriant, tropical growth.

The injury by all trees is shown in a somewhat similar way. In several cases the main (tallest) stems of oak trees were affected in such a way, that the leaves were large, bluish-green, with a vigorous growth in the secondary top shoots, while leaves of the side (shorter) stems showed slight injury. In several cases the leaves of the different stems of the same tree were measured. Number 64 for instance (plate 1) shows a number of leaves of the main stem which had an average length (measured from base to tip) of 30 cm. and a width of 24 cm., while the average length of a number of leaves of the side stems was only 15 cm. with a width of 12 cm. All leaves were taken from top shoots. The shape of the leaves, due to their great difference of dimensions, was accordingly different, the deep incisions more or less disappearing with increasing size. These large leaves were quite often bloated, the parenchyma bulging up between the primary and secondary veins, giving the leaves an unnatural, dropsical appearance (plate 1, fig. 1). Signs of injury of the oak trees started usually at the extreme end of the smaller veins. At the end of the tracheids occurred a very slight discoloration, probably due to the chlorine-ion entering the cell and changing the composition of the chlorophyll.

This slight discoloration extended until the leaf was spotted with yellow-brown regions. These regions touched each other after some time and gave the leaf a peculiar sickly appearance. If the injury showed at the extreme edges first, the leaf would turn brown at those places and curl; the center of the leaf might remain green for some time afterward, until the injury proceeded, resulting finally in brown closely curled leaves. In the former case the leaves may keep their usual flat surface until they drop. In both cases the leaves quite often become very glossy, dry out and become rubber-like. It is very difficult to break or tear these leaves. Sometimes the injury appears at first only in the primary and secondary veins, usually best seen on the under-side of the leaves. A light yellow discoloration becomes evident, giving the leaves an appearance of being temporarily covered with a fine yellow lace-work. The badly injured oak trees do not always shed their leaves, but as far as could be observed, the shedding took place in all cases where the leaves did not curl. Curling of the leaves as a rule appeared first on the lower branches, the leaves closest to the stem being attacked first. The injury spread gradually by attacking the higher leaves, and the leaves of the top shoots were affected last. This resulted in several cases in giving the trees in midsummer an appearance of autumn trees before heavy frost has removed the leaves of the end branches and top shoots.

Although the influence of sodium chloride on the birch trees was similar to that on the oaks, in some respects the results were different. Trees which were given smaller applications made vigorous growth, the leaves of the treated trees becoming larger and more glossy than those of the untreated trees. Instead of having a greater number of leaves, however, as in the case of oaks, the shoots quite often were elongated so much that the leaves seemed to be placed farther apart (no. 40, plate 3). Where only 1 or 2 pounds of the salt was applied, the trees were very luxuriant but when given 3, 4 or 5 pounds injurious effects were predominant. The leaves became slightly yellow-spotted and turned more or less suddenly into the typical autumn yellow color of birch trees. After dropping these leaves, tiny new shoots with light yellowish-colored leaves appeared, which stood usually close to the stems. These shoots were probably the latent buds forced to grow under the influence of the sodium chloride in an effort to survive. These small new shoots would soon turn black and dry out (plate 3). In some cases a third effort was made by the trees which sent out small new shoots from the roots. In nearly all cases these young stems suffered the same fate, as the tiny new "secondary" shoots.

Another peculiarity is shown in plates 3 and 4. The trees which produced the elongated branches looking as though they were outgrowing themselves, made a peculiar-shaped catkin. The catkins while in bloom were observed to have an abundance of stamens on the part nearest to the stems, while the upper part was relatively poor in stamens. This resulted in giving the catkins a conical, pointed shape. The writer was not able to detect an untreated

birch tree in this swamp which had similar-shaped catkins. They occurred only when the tree was moderately injured. Photographs (plate 4) of the dry catkins made in the middle of November show the same rather pronounced pointed shape, due to fewer and smaller seeds. The seeds of the tips of these catkins were smaller, the wings of the seeds toward the upper ends compared with the wings of the nutlets nearest to the stem were much smaller, the length and the width of the wings gradually decreasing toward the tip of the catkin. The salt seemed to shrivel these catkins in a similar way as it did the leaves. Whether the shriveling is due to the chlorine itself or to the preventing of the necessary food materials from entering the cells, could not be made out.

The soft-wooded maples were affected most quickly. Even when an application of only 1 pound of sodium chloride was made, a yellowish tint occurred in the leaves. This yellow tint changed rapidly into a black-brown by a heavier application. The leaves curled, became brown at the edges and finally dropped. The leaves at the end of the top shoots were quite regularly injured first, the other leaves of these branches following and the leaves of the lower branches, progressing in the same order, last. The brown edges were very dry, and broke easily by slight rubbing or when the wind shook the branches. If the wind moved the branches more vigorously, the leaves rattled as leaves will do which have remained on the trees in the fall. The new shoots of the secondary growth in the cases of slight and moderate injury were very short. They would cluster together, curling, and had a yellow-green color. The leaves and branches which survived never became larger than from one-tenth to three-tenths of the ordinary size of leaves (plate 6). The older injured leaves began gradually to drop soon after the heavier applications were given, and the tree made the usual effort to survive by sending out small new shoots from latent buds (plate 6). Those tiny branches clustered around the stem, became yellow, curled and dropped in nearly all cases.

If the height of the trees was taken into consideration it was quite evident that the injury decreased with the increasing size of the trees. A same application by weight would often do no harm, or injure only slightly a tall tree, while a lower one of the same species would be badly injured or sometimes killed.

It does not seem justifiable to describe in detail and draw conclusions from the behavior of the chestnut trees. Only comparatively few chestnuts were included and two of the five labelled "control" had a sickly appearance at the height of the season. Some of the same kind of trees standing in the swamp were also brownish and sickly. The data of the few cherry and dogwood trees in this experiment are given only for completeness of the record. All twenty-five trees marked "control" which were under constant observation, besides hundreds of others in the swamp were healthy throughout the entire season.

POSSIBLE EFFECTS OF CHLORINE

Whether it is a combination of the sodium and chlorine-ions or the chlorine-ion alone which causes the physiological responses within the cell, is not known. Bolin (4) concludes from his various fertilizer tests with a number of different soils, that the influence of the NaCl used, depended on its chlorine content, but not on its content of sodium. Söderbaum (29), experimenting with a poor sandy soil deficient in chlorine, admits that the remarkable increase might have been caused partly by the replacing of potassium by sodium, but the proportionate growth was beyond the amount of potassium and phosphorus added. He used three portions of soil, adding a complete fertilizer containing nitrogen in the form of $NaNO_3$, $(NH_4)_2SO_4$ or NH_4Cl. Sodium chloride was added in equivalent amounts to the $NaNO_3$. A noticeable increase in yield in behalf of the salt when added to the $NaNO_3$ and $(NH_4)_2SO_4$ was found, but not with NH_4Cl. There could not have been any hygroscopic action of the salt, as the pots were constantly watered. The investigator estimates an absorbed amount of 0.126 gm. of chlorine by the plants. These investigations were repeated and correlated by Söderbaum (30) in 1915. He makes the statement (page 20): "It can hardly be doubted any longer, the chlorine is an important factor in physiological changes."

Only hypotheses are given by some of the investigators concerning the way sodium chloride may react within the plant cell. The fact that there is a relation between the chlorine content and the accumulation of starch in potatoes, led Pfeffer and his students (26) to the suggestion that enzyme action might be the controlling factor. Tottingham (32) makes the supposition that the concentration of chlorine in the cell may exert marked controlling influences upon the activities of intracellular enzymes and if, in turn, many vital activities of the plant are controlled by enzyme action, the physiological responses might be brought about. From the data secured in our experiment it seems quite evident that the injurious and stimulating effects are caused mostly by the chlorine. Whether the chlorine combines with the chlorophyll or acts upon it in some other way to destroy it, can not be made out as yet. It is possible that the chlorine increases the acidity in the cell, which could accelerate the vital activities or enzymatic actions to a certain extent. By a too large increase of acidity the acceleration would change into a toxic action. The fact that applications of small amounts of NaCl which resulted in a luxuriant growth, giving the leaves an extremely dark color, change to a toxic effect whereby the leaves become gradually brown, when a greater dose is given, seems to support this supposition. Another observation seems to point in the same direction. A comparison between dead and live wood of trees of the same species, showed that the hydrogen-ion concentration differs. The pH values for live wood were lower than for dead wood, indicating that the acidity of these live trees was higher than of the dead trees. The preliminary studies on this part of the subject, however, are not yet far enough advanced to permit of drawing conclusions.

SUMMARY

Experiments were made upon 100 trees (oak, birch and maple) with sodium chloride; applications ranging from 1 to 10 pounds were made to individual trees.

Some trees showed injury as early as 6 weeks after the application, while after 10 weeks a number of trees were seriously injured and some dying. The leaves of these trees turned brown and curled. An examination made at the height of the season showed some marked external changes. Smaller applications of salt apparently acted as a fertilizer. The trees treated with a small application were making a vigorous growth, the leaves becoming very large and thick, having a dark blue-green color and glossy surface. Others elongated their branches making the distance between the leaves unusually wide. The first signs of toxicity appeared usually at the edges of the leaves at the extreme end of the tracheids, or in the primary and secondary veins. The injury spread gradually until the leaves had a spotted sickly appearance. After some time the leaves dried out with a rubber-like consistency. These leaves kept their flat and glossy surface and dropped from the branches. If the injury started at the edges of the leaves, they gradually turned brown, curled, but remained on the trees. When the injury appeared in the veins first a beautiful yellow-colored lace-work seemed to cover the under-side of the leaves.

Quite frequently the trees made an effort to survive by sending forth tiny new branches from latent buds. These small branches in nearly all cases turned black-brown and dried out.

Most of the trees which were given smaller applications made a secondary growth long before the untreated trees standing nearby.

Of the trees experimented with, the maple is the most easily affected by sodium chloride, followed by the birch and finally by the oaks.

The rate of injury seems to be dependent upon the height of the trees. The higher trees were more resistant than the lower ones of the same species.

It is possible that the chlorine increases the acidity in the plant cell, accelerating or harming the vital activities, according to the amount employed.

The fact that a small amount of sodium chloride acts as a fertilizer or as a stimulant for trees and shrubs, may lead to the more general use of common rock salt for certain plants, while the toxic effects of the larger applications might be employed in the eradication of weeds and the clearing of farm land from live stumps.

ACKNOWLEDGMENT

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PLATE 1

FIG. 1. Two top branches of the same oak tree showing the difference in length and width of leaves. The shape of the leaves is changed, because of the great difference in dimensions. The largest leaves show unnatural, vigorous growth, with the parenchyma bulging up between the primary and secondary veins.

FIG. 2. Another view of the smaller branch in figure 1, showing signs of injury starting with the lowest leaves of side branches and top shoots; leaves beginning to curl.

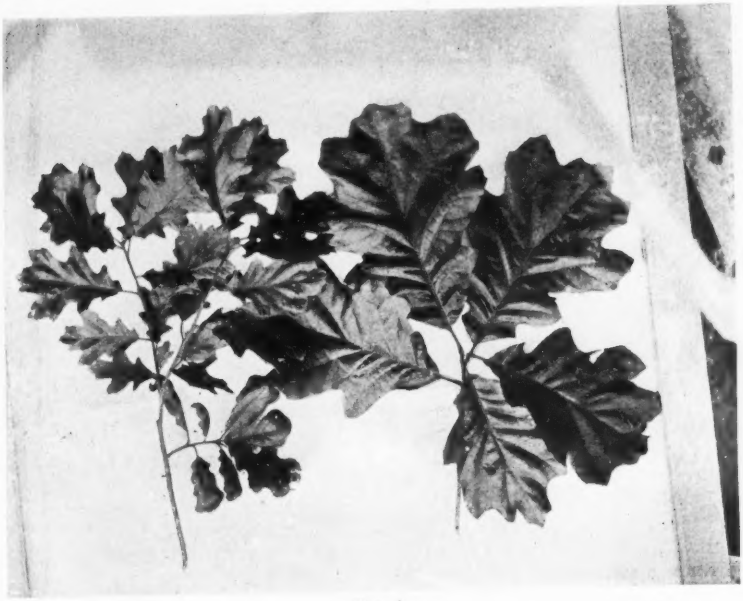

FIG. 1

FIG. 2

PLATE 2

FIG. 1. Oak branch with leaves which have a sickly appearance. Injury starts at the extreme end of the tracheids and proceeds. Leaves do not curl.

FIG. 2. Oak branch showing injury which results in the dropping of the leaves; this gives the tree an autumn-like appearance.

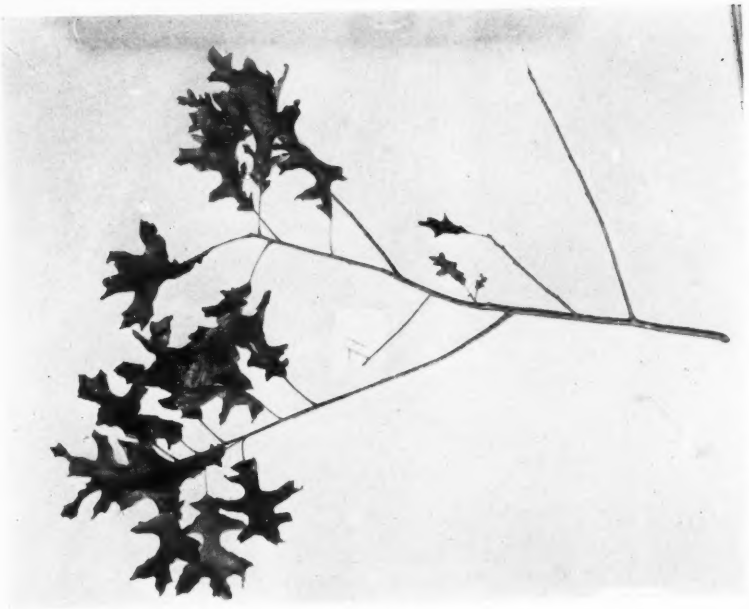

FIG. 2

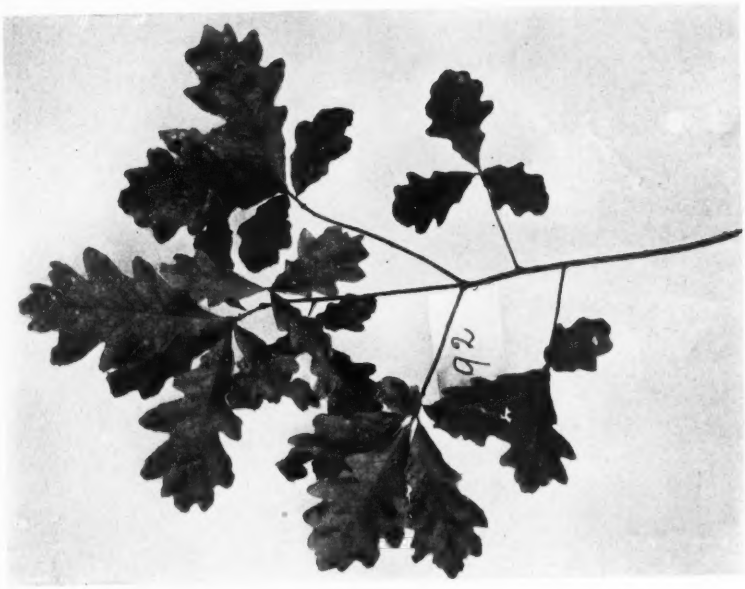

FIG 1

PLATE 3

FIG. 1. Birch with elongated shoots as result of the application of NaCl. Catkins have a conical shape.

FIG. 2. Birch with shoots from latent buds, which turn black-brown, dry out and drop off. Leaves from last year's buds have dropped previously.

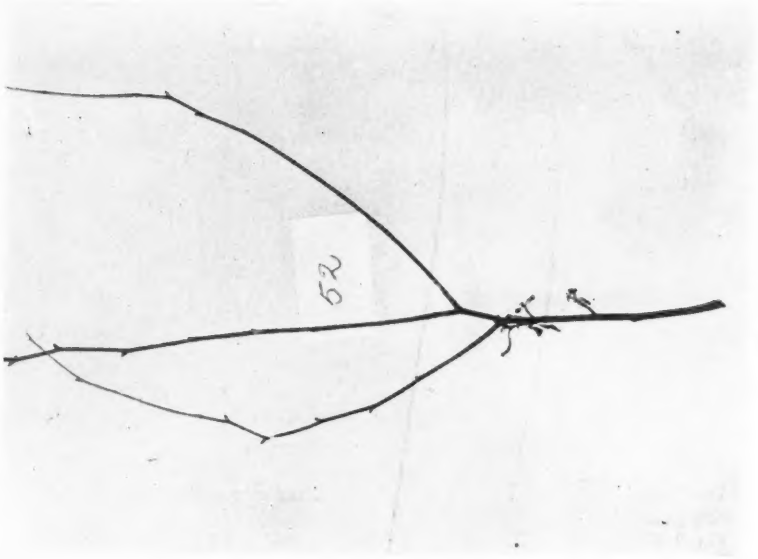

FIG. 2

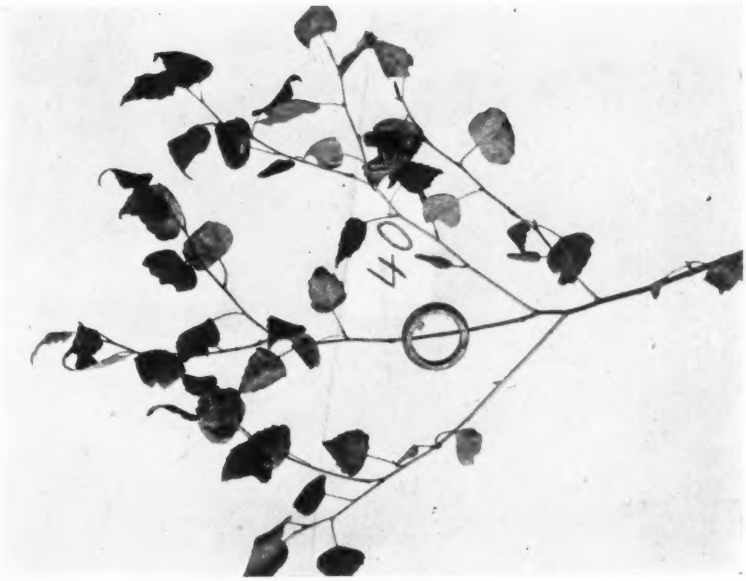

FIG. 1

PLATE 4

FIG. 1. Catkins on branches of birch trees treated and untreated with NaCl; the former having a conical, pointed shape.

FIG. 2. Catkins removed from branches; about two-thirds actual size. Conical catkins have fewer and smaller nutlets toward the tips.

FIG. 1 (Upper)

FIG. 2 (Lower)

PLATE 5

FIG. 1. Branch of treated chestnut tree.

FIG. 2. Branch of maple showing beginning of injury on the end leaves of the shoots. The highest leaves are affected first.

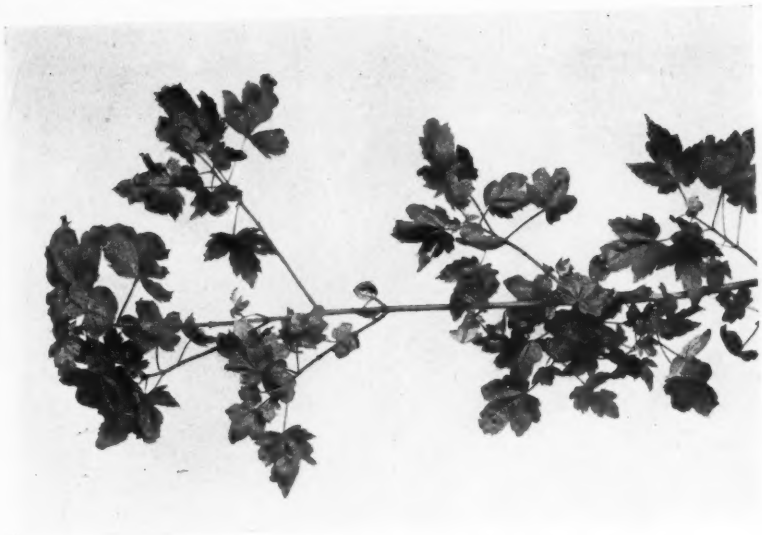

FIG. 2

FIG. 1

PLATE 6

FIG. 1. Injured maple at a further stage than in plate 5. These leaves dry out and break by slight rubbing or by swaying in the wind.

FIG. 2. Tiny shoots from latent buds made in an effort to survive. These leaves which never grew larger than one-tenth to three-tenths of the usual size, became yellow and curled, and dropped off.

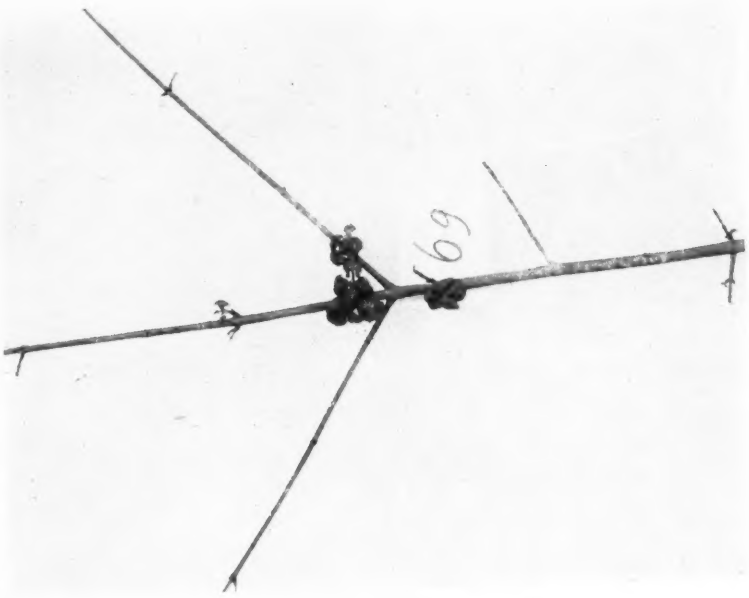

FIG. 2

FIG. 1

PLATE 7

FIG. 1. Treated birch dying on August 7.

FIG. 2. Treated oak with autumn-like appearance. All leaves nearest to the main stem have dropped.

FIG. 3. Maple which made large leaves in secondary growth. Older leaves all dropped. Only the new leaves on the top shoots remained.

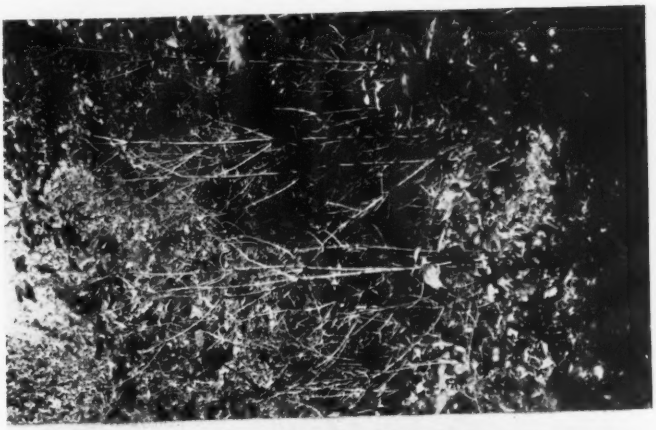

FIG. 3

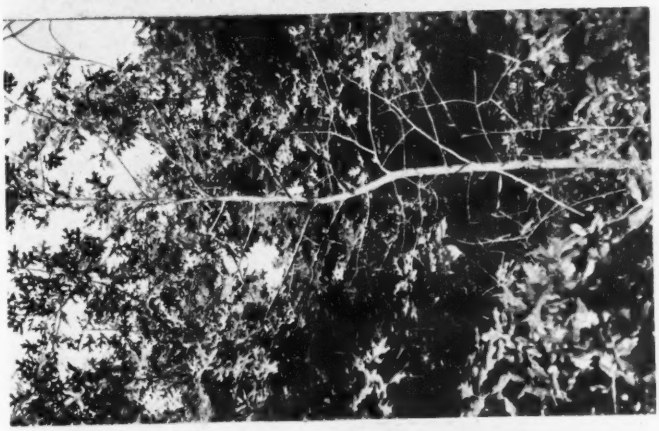

FIG. 2

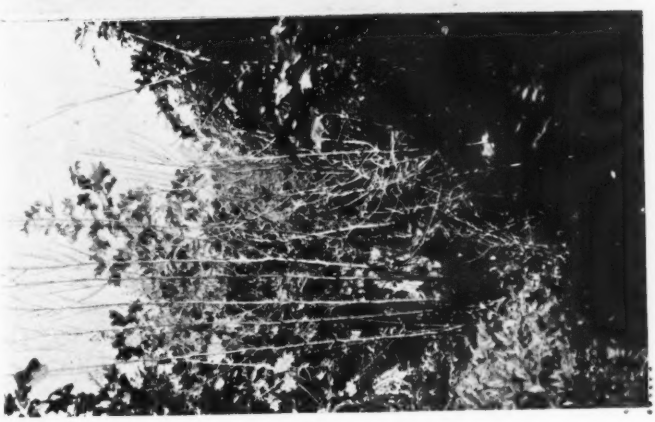

FIG. 1